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ENGINEERING DATA ON NEW AEROSPACE STRUCTURAL MATERIALS

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TECHNICAL REPORT AFML-TR-77-198
Final Report for Period February 1976 to September 1977

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AIR FORCE MATERIALS LABORATORY
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This technical report has been reviewed and is approved for publication.

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Mechanical Properties	Aluminum Alloys	Ti-6Al-4V
Fatigue Properties	Titanium Alloys	Ti-10V-2Fe-3Al
Creep Properties	High Strength Steel Alloys	Ti-6Al-2Sn-4Zr-2Mo
Chemical Composition	7175	
Physical Properties	7050	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The major objectives of this program were to evaluate newly developed materials of interest to the Air Force for potential airframe structural usage, and to provide "data sheet"-type presentations of engineering data for these materials. The materials effort on this program concentrated on MP 159 Multiphase Bar, Ti-6Al-2Sn-4Zr-2Mo castings, 7175-T73511 and -T76511 extrusions, 7050-T73 Extrusions, Ti-6Al-4V PM Product, Ti-6Al-4V superplastically formed product, Ti-10V-2Fe-3Al Alloy Bar, and 4330M Steel Forgings. The properties investigated include tension, compression, shear, bearing, impact, fracture toughness, fatigue, creep and stress-rupture, and stress corrosion at selected temperatures.

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FOREWORD

This report was prepared by Battelle's Columbus Laboratories, Columbus, Ohio, under Contract F33615-75-C-5065. This contract was performed under Project No. 7381, "Materials Applications", Task No. 738106, "Engineering and Design Data". The work was administered under the direction of the Air Force Materials Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, by Mr. Clayton Harmsworth (AFML/MXA), Technical Manager.

This final report covers work conducted from February 1976, to September 1977. This report was submitted by the author on October 5, 1977.

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SECTION I

INTRODUCTION

The selection of materials to most effectively satisfy new environmental requirements and increased design load requirements for advanced Air Force weapons systems is of vital importance. A major difficulty that design engineers encounter, particularly for newly developed materials, materials processing, and product forms, is a lack of sufficient engineering data to effectively evaluate the relative potential of these developments for a particular application.

In recognition of this need, the Air Force has sponsored several programs at Battelle's Columbus Laboratories to provide comparative engineering data for newly developed materials. The materials included in these evaluation programs were carefully selected to insure that they were either available or could become quickly available on request and that they would represent potentially attractive alloy projections for weapons systems usage. The results of these programs have been published in seven technical reports, AFML-TR-67-418, AFML-TR-68-211, AFML-TR-70-252, AFML-TR-71-249, AFML-TR-72-196, Volumes I and II, AFML-TR-73-114, and AFML-TR-75-97.

This technical report is a result of the continuing effort to relieve the above situation and to stimulate interest in the use of newly developed alloys, or new processing techniques and product forms for older alloys, for advanced structures.

The materials evaluated under this program are as follows:

1) MP 159 work strengthened and aged bar
2) Ti-6Al-2Sn-4Zr-2Mo castings
3) 7175-T73511 Aluminum Alloy extrusions
4) 7050-T73 Aluminum Alloy extrusions
5) Ti-6Al-4V powder metallurgy product
6) Ti-6Al-4V superplastically formed product
7) Ti-10V-2Fe-3Al solution treated and aged bar
8) 7175-T76511 Aluminum Alloy extrusions
9) 4330M steel forgings.

A comprehensive engineering evaluation was conducted on each of the above materials. Upon completion of each evaluation, a "data sheet" was issued to make the information immediately available to potential users rather than defer publication to the end of the contract term and this summary technical report. These data sheets are reproduced as Appendix C of this report.

Detailed information concerning the properties of interest, test techniques, and specimen types is contained in Appendices A and B of this report.

MP 159 Multiphase Alloy

MP 159 alloy is a recent addition to the multiphase family of alloys developed by the Latrobe Steel Company. It possesses a unique combination of ultrahigh strength, ductility, and corrosion resistance. Through work strengthening and aging, the alloy exhibits tensile ultimate strength levels in excess of 265 ksi while maintaining reduction of area values greater than 30 percent. Excellent strength and ductility are also evident at elevated temperatures up to about 1200 F. This alloy also displays excellent resistance to crevice and stress corrosion in various hostile environments. Typical uses are fasteners and jet engine components.

The material used for this evaluation was 0.766-inch-diameter round bar from Latrobe Heat No. C52377. The material had the following composition:

Chemical Composition	Percent
Carbon	.014
Silicon	.01
Manganese	.01
Sulfur	.004
Phosphorus	.004
Iron	8.77
Chromium	18.95
Columbian	.64
Molybdenum	7.09
Cobalt	34.78
Titanium	2.99
Aluminum	.22
Nickel	Balance .

Processing and Heat Treating

The material was received in the cold-drawn/as-drawn condition (48 percent work strengthened). After machining, the specimens received a 1225 F, 4-hour, air-cool aging treatment. Since the material was round bar and all specimens were taken from the longitudinal direction, no specimen layout is shown.

Test Results

Tension. Tests were conducted at room temperature, 800 F, and 1200 F for longitudinal specimens. Test results are presented in Table I. Typical stress-strain curves at temperature are shown in Figure 1. Effect-of-temperature curves are presented in Figure 4.

Compression. Tests were conducted at room temperature, 800 F, and 1200 F for longitudinal specimens. Test results are presented in Table II. Typical stress-strain and tangent-modulus curves are shown in Figures 2 and 3. Effect-of-temperature curves are shown in Figure 5.

Bearing. The round bar was not of sufficient size for bearing specimens.

Shear. Pin shear tests were performed at room temperature, 800 F, and 1200 F. Test results are presented in Table III. Effect-of-temperature curves are shown in Figure 6.

Impact. Test results for longitudinal Charpy specimens at room temperature are presented in Table IV.

Fracture Toughness. The material was not of sufficient size for K_{Ic} tests.

Fatigue. Axial load fatigue tests at a stress ratio of R = 0.1 were conducted for both unnotched and notched longitudinal specimens at room temperature, 800 F, and 1200 F. Test results are shown in Tables V and VI. S-N curves are presented in Figures 7 and 8.

Creep and Stress-Rupture. Tests were conducted on longitudinal specimens at 800 F and 1200 F. Tabular test results are given in Table VII. Log-stress versus log-time curves are shown in Figure 9.

Stress Corrosion. Tests were conducted as described in the experimental procedures section of this report. No failures or cracks occurred in the test duration.

Thermal Expansion. The coefficient of thermal expansion for this alloy is 8.7×10^{-6} in./in./F (80 - 1200 F).

Density. The density of this material is 0.302 lb/in^3.

TABLE I. RESULTS OF TENSILE TESTS ON WORK STRENGTHENED AND AGED MP 159 ALLOY BAR

Specimen Number	Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 2 Inches, percent	Reduction in Area, percent	Tensile Modulus, 10^3 ksi
		Room Temperature			
1-1	283.0	279.0	4.0	24	33.6
1-2	278.8	274.5	8.0	29	32.4
1-3	276.6	274.6	7.0	30	33.8
Average	279.5	276.0	6.3	27.7	33.3
		800 F			
1-4	235.0	231.0	4.5	29	30.1
1-5	240.0	234.1	5.0	30	29.6
1-6	239.0	232.0	8.0	28	31.0
Average	238.0	232.3	5.8	29.0	30.2
		1200 F			
1-7	226.0	211.0	2.0	12	26.9
1-8	224.6	215.0	6.0	18	27.1
1-9	217.0	211.0	7.0	17	25.0
Average	222.5	212.3	5.0	15.7	26.3

TABLE II. RESULTS OF COMPRESSION TESTS ON WORK STRENGTHENED AND AGED MP 159 ALLOY BAR

Specimen Number		0.2 Percent Offset Yield Strength, ksi	Compressive Modulus, 10^3 ksi
		Room Temperature	
2-1		285.6	35.8
2-2		280.9	34.6
2-3		284.0	35.0
	Average	283.5	35.1
		800 F	
2-4		234.2	30.9
2-5		230.0	29.9
2-6		237.6	30.0
	Average	233.9	30.3
		1200 F	
2-7		215.5	30.4
2-8		217.9	28.6
2-9		212.0	27.9
	Average	215.1	29.0

TABLE III. RESULTS OF PIN SHEAR TESTS ON WORK STRENGTHENED AND AGED MP 159 ALLOY BAR

Specimen Number		Shear Ultimate Strength, ksi
	Room Temperature	
4-1		183.9
4-2		190.6
4-3		187.2
	Average	187.2
	800 F	
4-4		166.0
4-5		172.8
4-6		159.2
	Average	166.0
	1200 F	
4-7		125.7
4-8		125.1
4-9		128.1
	Average	126.3

TABLE IV. CHARPY IMPACT TEST RESULTS AT ROOM TEMPERATURE FOR LONGITUDINAL SPECIMENS OF WORK STRENGTHENED AND AGED MP 159 ALLOY BAR

Specimen Number		Energy, ft/lbs
10L-1		40.0
10L-2		41.0
10L-3		44.5
10L-4		41.0
10L-5		44.0
	Average	42.1

TABLE V. AXIAL LOAD FATIGUE TEST RESULTS FOR UNNOTCHED MP 159 ALLOY BAR (LONGITUDINAL, R = 0.1)

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
	Room Temperature	
5-3	240	38,310
5-2	220	62,720
5-1	200	159,270
5-4	190	204,900
5-5	175	425,090
5-6	160	782,460
5-7	140	2,116,000
5-8	130	3,769,270
5-9	120	8,727,900
	800 F	
5-69	220	80,200
5-71	200	156,400
5-68	160	946,800
5-70	140	4,066,000
5-72	140	3,486,400
5-73	135	3,029,700
5-74	130	5,354,000
	1200 F	
5-65	220	150
5-66	200	199,500
5-62	180	28,600(a)
5-64	180	571,700
5-61	160	(a)
5-67	160	2,115,400
5-63	140	10,000,000(b)

(a) Failed at thermocouple.

(b) Did not fail.

TABLE VI. AXIAL LOAD FATIGUE TEST RESULTS FOR NOTCHED (K_t = 3.0) MP 159 ALLOY BAR (LONGITUDINAL, R = 0.1)

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
	Room Temperature	
5-29	140	7,570
5-30	100	26,590
5-31	80	62,180
5-36	70	95,030
5-32	60	207,860
5-37	50	571,940
5-33	40	947,310
5-35	30	13,061,000[a]
5-34	20	12,027,300[a]
	800 F	
5-50	100	14,600
5-46	90	22,000
5-43	80	51,900
5-49	70	58,500
5-48	70	211,700
5-47	60	385,300
5-52	55	8,943,100
5-44	50	12,300,000[a]
	1200 F	
5-40	90	8,300
5-45	80	17,000
5-41	75	59,800
5-39	70	121,400
5-42	65	4,959,800
5-38	60	10,000,000[a]

(a) Did not fail.

TABLE VII. SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES FOR MP159 ALLOY ROUND BAR

Specimen Number	Stress, ksi	Temperature, F	Hours to Indicated Creep Deformation, percent: 0.1	0.2	0.5	1.0	2.0	Initial Strain, percent	Rupture Time, hours	Elongation in 2 Inches, percent	Reduction of Area, percent	Minimum Creep Rate, percent
3-1	198	800	--	--	--	--	--	--	On Loading	8.1	41.7	--
3-6	195	800	4	45	1250(a)	--	--	1.021	839.9(b)	1.425	--	0.00017
3-3	180	800	3	105	2500(a)	--	--	0.811	452.5(b)	1.078	--	--
3-10	175	800	6	590	3100(a)	--	--	0.714	523.0(b)	0.909	--	0.00012
3-8	160	800	160	3450(a)	--	--	--	0.607	1628.8(b)	0.776	--	0.000017
3-4	175	1200	0.2	0.6	1.0	5.4	9	0.836	16.2	20.7	45.7	0.17
3-2	150	1200	0.7	2.5	12.5	34	60	0.700	92.4	21.5	47.8	0.022
3-5	120	1200	3.5	16	115	290	415	0.548	607.6	19.3	35.5	0.0024
3-9	100	1200	14	80	435(a)	--	--	0.508	265.1(b)	0.871	--	0.0008
3-7	75	1200	97	660	2700(a)	--	--	0.303	840.6(b)	0.530	--	0.00025

(a) Estimated.

(b) Test discontinued.

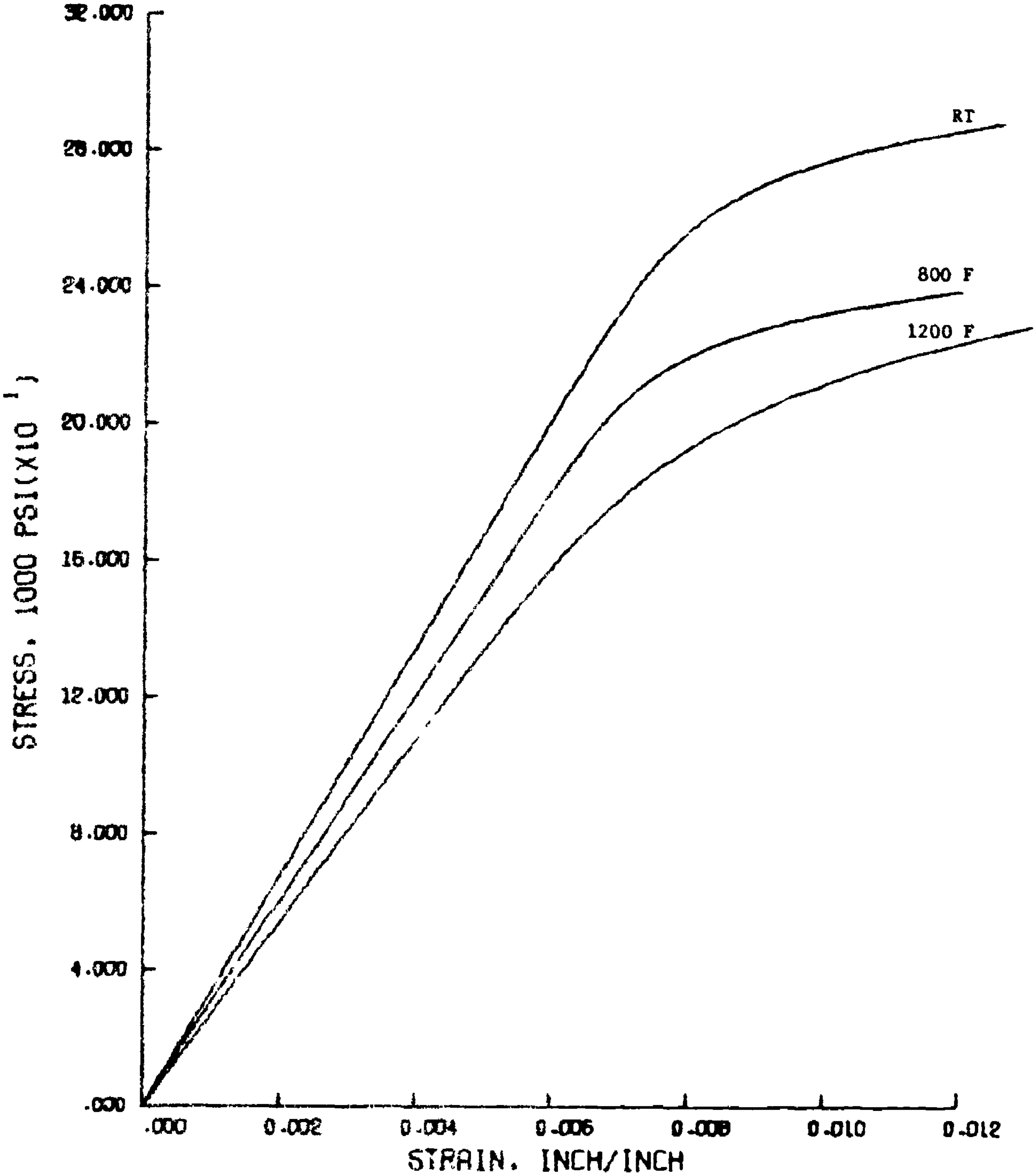

FIGURE 1. TYPICAL TENSILE STRESS-STRAIN CURVES AT TEMPERATURE FOR MP 159 ALLOY BAR

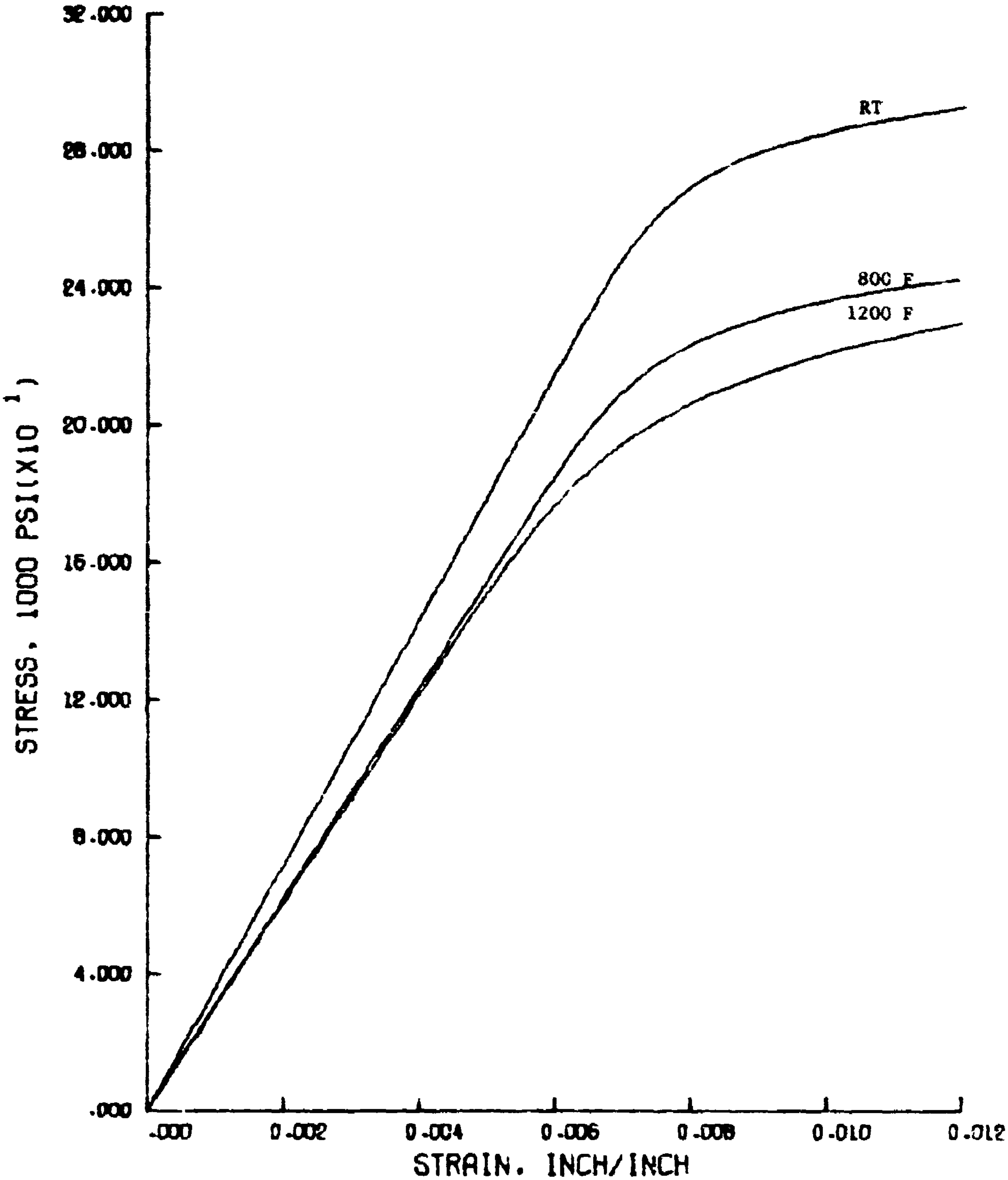

FIGURE 2. TYPICAL COMPRESSIVE STRESS-STRAIN CURVES AT TEMPERATURE FOR MP 159 ALLOY BAR

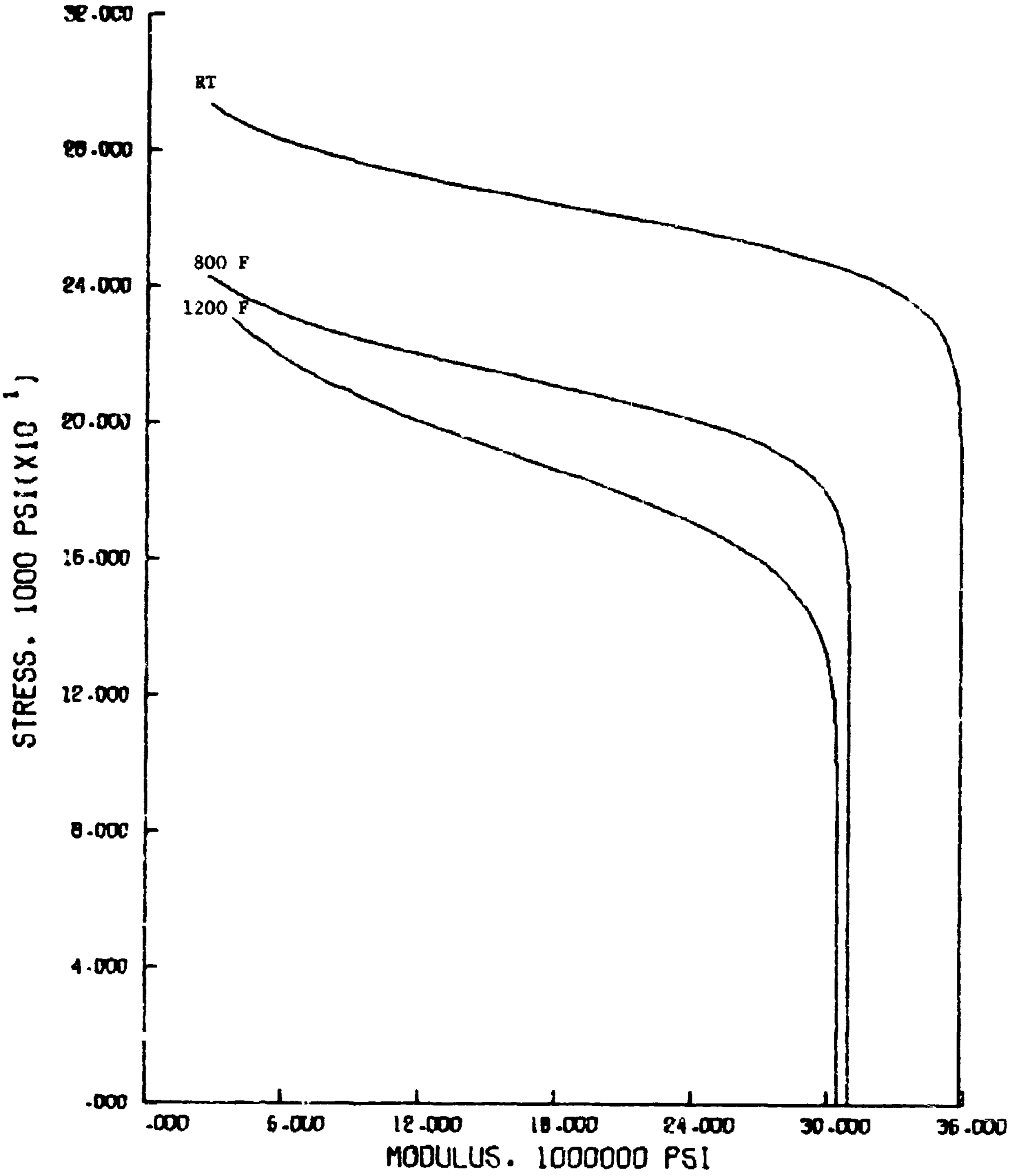

FIGURE 3. TYPICAL COMPRESSIVE TANGENT-MODULUS CURVES AT TEMPERATURE FOR MP 159 ALLOY BAR

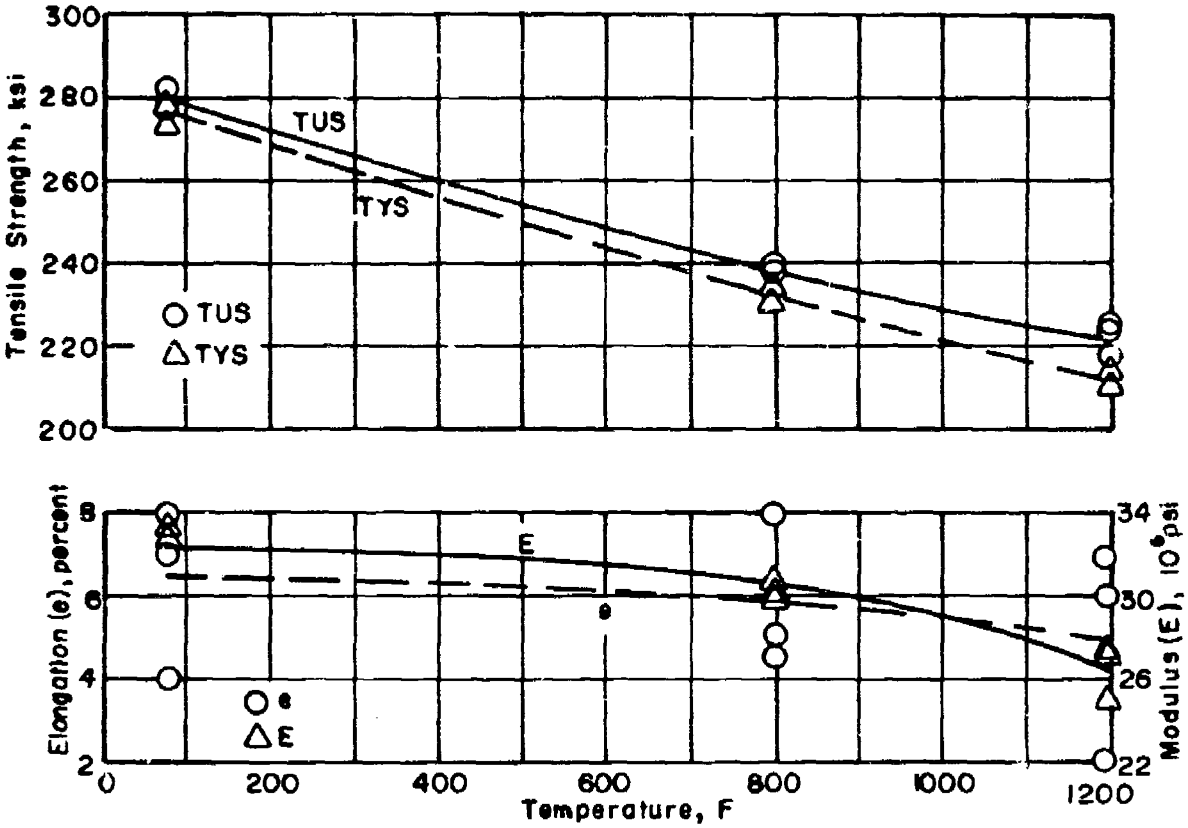

FIGURE 4. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF WORK STRENGTHENED AND AGED MP159 ALLOY BAR

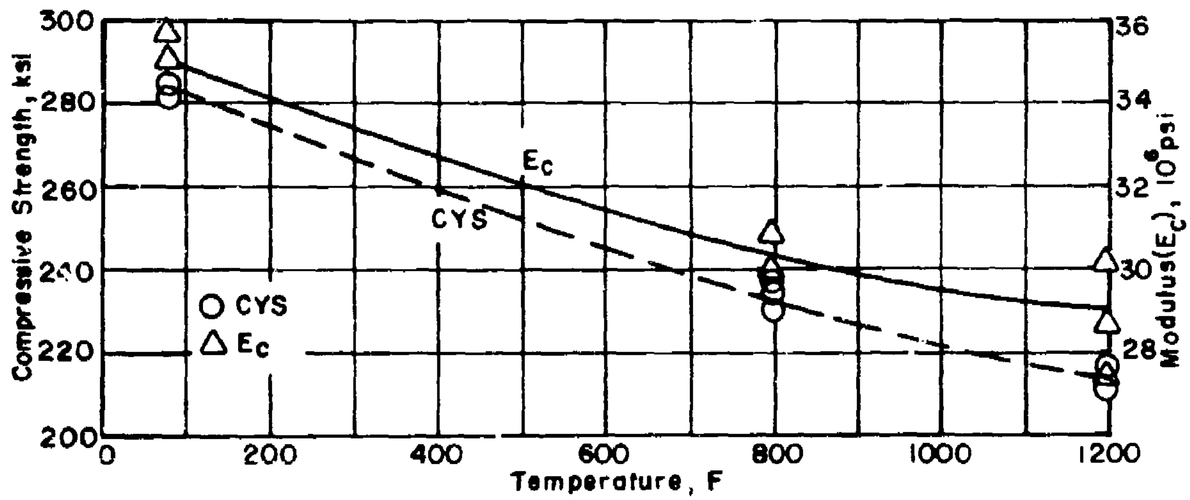

FIGURE 5. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF WORK STRENGTHENED AND AGED MP159 ALLOY BAR

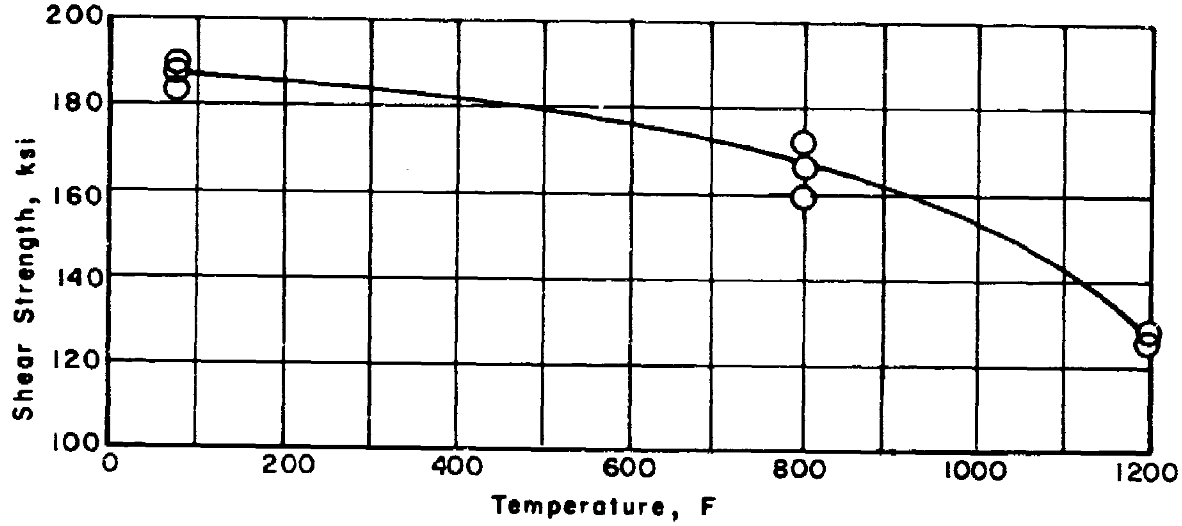

FIGURE 6. EFFECT OF TEMPERATURE ON THE SHEAR PROPERTIES OF WORK STRENGTHENED AND AGED MP159 ALLOY BAR

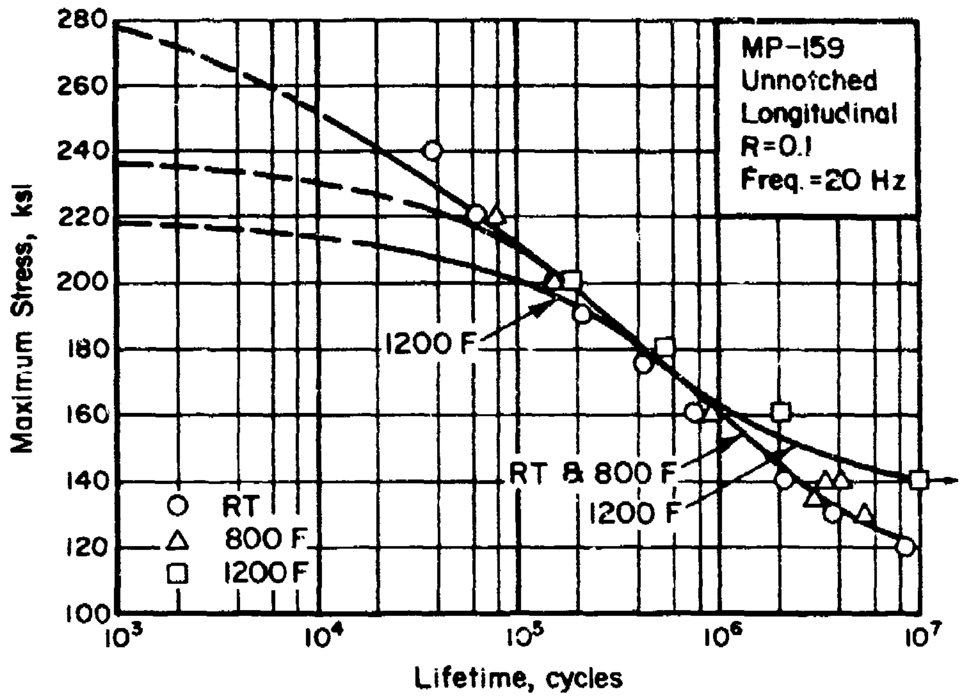

FIGURE 7. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED WORK STRENGTHENED AND AGED MP159 ALLOY BAR

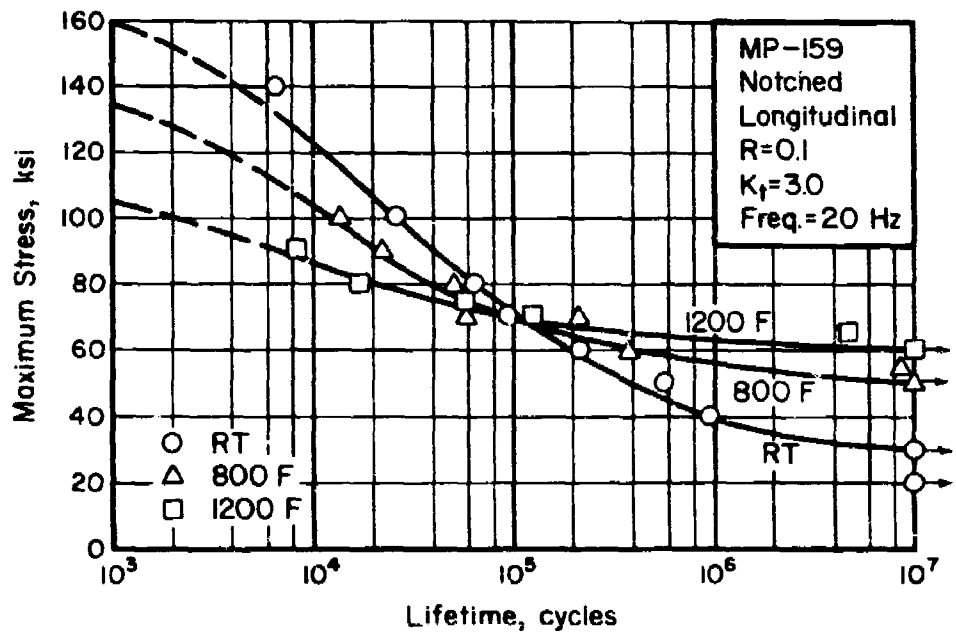

FIGURE 8. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) WORK STRENGTHENED AND AGED MP159 ALLOY BAR

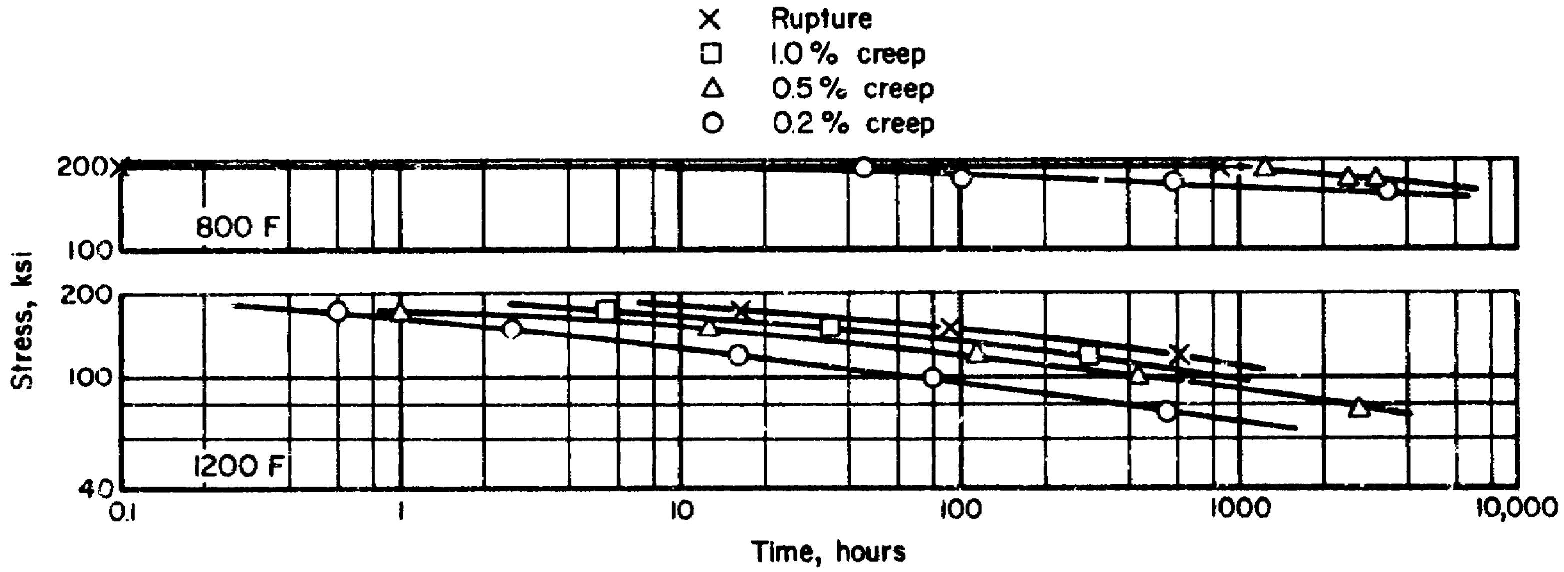

FIGURE 9. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR MP 159 ALLOY BAR

Ti-6Al-2Sn-4Zr-2Mo Alloy Castings

Material Description

This alloy is considered a super-alpha titanium alloy having an alpha-stabilized Ti-Al matrix solid solution strengthened by the additions of tin and zirconium. It has been primarily used in jet engine compressor parts and air-frame skin components. It has good strength properties at elevated temperatures, and good creep properties and corrosion resistance.

Because of the current interest in titanium castings, the material chosen for this evaluation was 6-inch x 6½-inch cast wedges (tapered plates) manufactured by TiTech International and supplied by Rockwell International, Columbus Division. The composition was as follows:

Chemical Composition	Percent
C	0.018
O	0.168
H	0.0047
N	0.013
Al	6.02
Sn	2.04
Zr	3.80
Mo	2.07
Fe	0.010
Si	0.05

Processing and Heat Treating

The material was evaluated in the as-received as-cast condition. Specimens were sectioned from about 24 wedges.

Test Results

Tension. Tests were conducted at room temperature, 400 F, and 800 F. Test results are presented in Table VIII. Typical stress-strain curves are shown in Figure 10. Effect-of-temperature curves are shown in Figure 13.

Compression. Compression tests were also conducted at room temperature, 400 F, and 800 F. Results are shown in tabular form in Table IX. Typical stress-strain and tangent-modulus curves are shown in Figures 11 and 12. Effect-of-temperature curves are presented in Figure 14.

Shear. Pin shear tests were performed at room temperature, 400 F, and 800 F. Test results are presented in Table X. Effect-of-temperature curves are shown in Figure 15.

Bearing. Bearing tests at e/D = 1.5 and e/D = 2.0 were conducted at room temperature, 400 F, and 800 F. Test results are presented in Table XI and effect-of-temperature curves are shown in Figure 16.

Impact. Results of Charpy impact tests at room temperature are given in Table XII.

Fracture Toughness. Six compact-tension-type tests were conducted at room temperature. Only two of these were valid per ASTM E399. The average K_{Ic} for these tests was 59.4 ksi$\sqrt{in.}$ In order to more fully characterize the material, two fatigue-crack-propagation specimens were fabricated and tested. These test results are shown in Figure 17.

Fatigue. Axial load fatigue tests were performed at room temperature, 700 F, and 900 F for unnotched and notched specimens. Results are tabulated in Tables XIII and XIV and presented as S-N-type curves in Figures 18 and 19.

Creep and Stress-Rupture. Tests were conducted at 700 F and 900 F. Tabular test results are given in Table XV. Log-stress versus log-time curves are presented in Figure 20.

Thermal Expansion. The coefficient of thermal expansion for this material is 5.4×10^{-6} in/in/F (80 - 800 F).

Stress Corrosion. Bolt-loaded cantilever beam type specimens were used in an attempt to measure K_{Iscc}. No appreciable crack growth could be obtained.

Density. The density of this material is 0.163 lb/in^3.

TABLE VIII. RESULTS OF TENSILE TESTS ON AS-CAST Ti-6Al-2Sn-4Zr-2Mo ALLOY CASTINGS

Specimen Number	Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 1-Inch percent	Reduction in Area, percent	Tensile Modulus, 10^3 ksi
		Room Temperature			
1-1	134.7	120.7	11.0	18.6	17.0
1-2	135.5	121.0	11.0	18.3	17.4
1-3	135.3	121.4	8.0	14.8	17.4
Average	135.2	121.0	10.0	17.2	17.3
		400 F			
1-4	112.7	87.7	7.5	13.5	16.3
1-5	105.9	81.9	13.0	24.0	16.3
1-6	112.4	88.1	10.0	17.9	15.1
Average	110.3	85.9	10.2	18.5	15.9
		800 F			
1-7	92.0	68.2	12.5	24.1	14.2
1-8	101.0	73.5	12.5	22.9	15.5
1-9	91.0	66.6	12.5	24.0	15.1
Average	94.7	69.4	12.5	23.7	14.9

TABLE IX. RESULTS OF COMPRESSION TESTS ON AS-CAST Ti-6Al-2Sn-4Zr-2Mo ALLOY CASTINGS

Specimen Number	0.2 Percent Offset Yield Strength, ksi	Compressive Modulus, 10^3 ksi
	Room Temperature	
2-1	144.3	17.3
2-2	130.3	17.1
2-3	132.1	16.9
	Average 135.6	17.1
	400 F	
2-4	98.0	15.5
2-5	89.3	16.4
2-6	97.2	16.3
	Average 94.8	16.1
	800 F	
2-7	79.2	14.9
2-8	75.4	14.7
2-9	77.6	13.9
	Average 77.4	14.5

TABLE X. RESULTS OF PIN SHEAR TESTS ON AS-CAST Ti-6Al-2Sn-4Zr-2Mo ALLOY CASTINGS

Specimen Number	Ultimate Shear Strength, ksi
Room Temperature	
4-1	93.8
4-2	95.0
4-3	97.0
Average	95.3
400 F	
4-4	71.8
4-5	73.7
4-6	73.8
Average	73.1
800 F	
4-7	64.6
4-8	62.0
4-9	60.9
Average	62.5

TABLE XI. RESULTS OF BEARING TESTS AT e/D = 1.5 AND e/D = 2.0 FOR AS-CAST Ti-6Al-2Sn-4Zr-2Mo ALLOY

Specimen Number		Bearing Ultimate Strength, ksi		Bearing Yield Strength, ksi	
		e/D = 1.5	e/D = 2.0	e/D = 1.5	e/D = 2.0
		Room Temperature			
B-1		240.7	291.3	209.6	246.1
B-2		230.4	303.8	207.6	257.2
B-3		193.6	295.0	169.2	252.3
	Average	221.6	296.7	195.5	251.9
		400 F			
B-4		182.0	221.6	152.8	180.5
B-5		191.7	230.3	161.3	188.0
B-6		184.8	226.4	154.1	186.7
	Average	186.2	226.0	156.1	185.1
		800 F			
B-7		159.4	201.6	125.5	153.2
B-8		159.5	199.2	131.9	155.4
B-9		160.0	198.8	136.0	155.3
	Average	159.6	199.9	131.1	154.6

TABLE XII. RESULTS OF IMPACT TESTS AT ROOM TEMPERATURE ON AS-CAST Ti-6Al-2Sn-4Zr-2Mo ALLOY CASTINGS

Specimen Number		Energy, ft/lbs
10-1		16.0
10-2		15.0
10-3		14.0
10-4		15.5
10-5		16.0
10-6		13.0
	Average	14.9

TABLE XIII. RESULTS OF AXIAL LOAD FATIGUE TESTS FOR UNNOTCHED AS-CAST Ti-6Al-2Sn-4Zr-2Mo ALLOY CASTINGS AT A RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	Cycles to Failure
	Room Temperature	
5-19	120	3,200
5-2	100	24,200
5-1	80	30,500
5-4	70	52,300
5-3	60	106,700
5-5	50	1,322,900
5-6	50	1,934,900
5-7	40	866,400
5-20	35	4,799,000
	700 F	
5-25	100	100
5-8	80	25,200
5-12	70	101,800
5-9	60	31,700
5-13	60	62,200
5-10	50	81,600
5-11	40	2,316,400
5-23	35	10,000,000 (a)
	900 F	
5-18	90	14,800
5-14	80	14,800
5-17	70	10,800
5-16	60	175,400
5-15	50	2,742,300
5-21	40	733,100
5-22	30	10,000,000 (a)

(a) Did not fail.

TABLE XIV. RESULTS OF AXIAL LOAD FATIGUE TESTS FOR NOTCHED (K_t = 3.0) AS-CAST Ti-6Al-2Sn-4Zr-2Mo ALLOY CASTINGS AT A RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	Cycles to Failure
	Room Temperature	
5N-4	80	9,600
5N-1	70	13,200
5N-5	60	26,100
5N-2	50	39,300
5N-6	40	256,200
5N-3	30	10,000,000 (a)
	700 F	
5N-9	70	8,100
5N-7	60	21,800
5N-10	55	47,700
5N-8	50	39,000
5N-11	45	119,000
5N-12	40	737,500
5N-19	35	1,476,400
5N-21	30	10,000,000 (a)
	900 F	
5N-26	70	3,900
5N-15	60	14,100
5N-16	55	21,000
5N-13	50	72,200
5N-17	45	201,000
5N-14	40	1,090,800
5N-18	35	1,568,200
5N-20	30	10,000,000 (a)

(a) Did not fail.

TABLE XV. SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES FOR Ti-6Al-4Zr-2Mo CASTINGS

Specimen Number	Stress, ksi	Temperature, F	Hours to Indicated Creep Deformation, percent: 0.1	0.2	0.5	1.0	2.0	Initial Strain, percent	Rupture Time, hours	Elongation in 2 Inches, percent	Reduction of Area, percent	Minimum Creep Rate, percent
3-1	100	700	--	--	--	--	--	--	On Loading	10.4	25.4	--
3-10	95	700	--	--	--	--	--	--	On Loading	8.2	23.8	--
3-4	90	700	270	800	--	--	--	2.444	1132.8 (b)	2.684	--	0.0002
3-2	80	700	55	340	4000 (a)	--	--	1.455	302.7 (b)	1.675	--	0.00008
3-8	70	700	190	4600 (a)	--	--	--	0.715	1316.2 (b)	0.882	--	0.00001
3-6	90	900	0.02	0.05	0.17	0.47	1.5	6.430	4.1	12.6	26.6	0.92
3-5	80	900	0.9	3.0	20	66	154	0.963	544.0	17.8	26.0	0.010
3-3	60	900	4.5	22	232	630	1600 (a)	0.452	626.2 (b)	1.396	--	0.0011
3-9	45	900	14	78	1030 (a)	--	--	0.474	649.1 (b)	0.881	--	0.00024
3-7	35	900	165	975	4300 (a)	--	--	0.018	955.7 (b)	0.217	--	0.00009

(a) Estimated.

(b) Test discontinued.

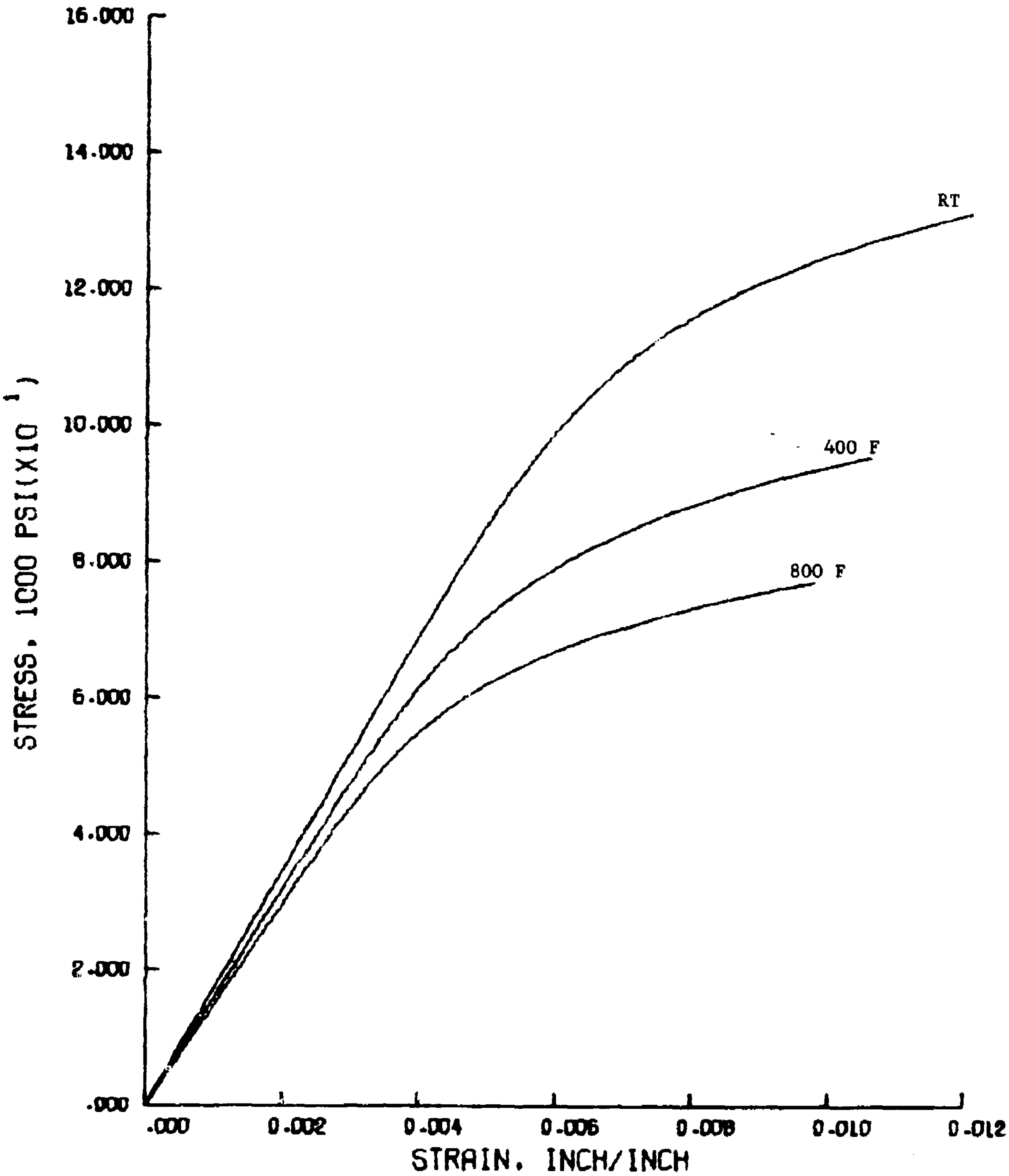

FIGURE 10. TYPICAL TENSILE STRESS-STRAIN CURVES AT TEMPERATURE FOR Ti-6Al-2Sn-4Zr-2Mo ALLOY CASTINGS

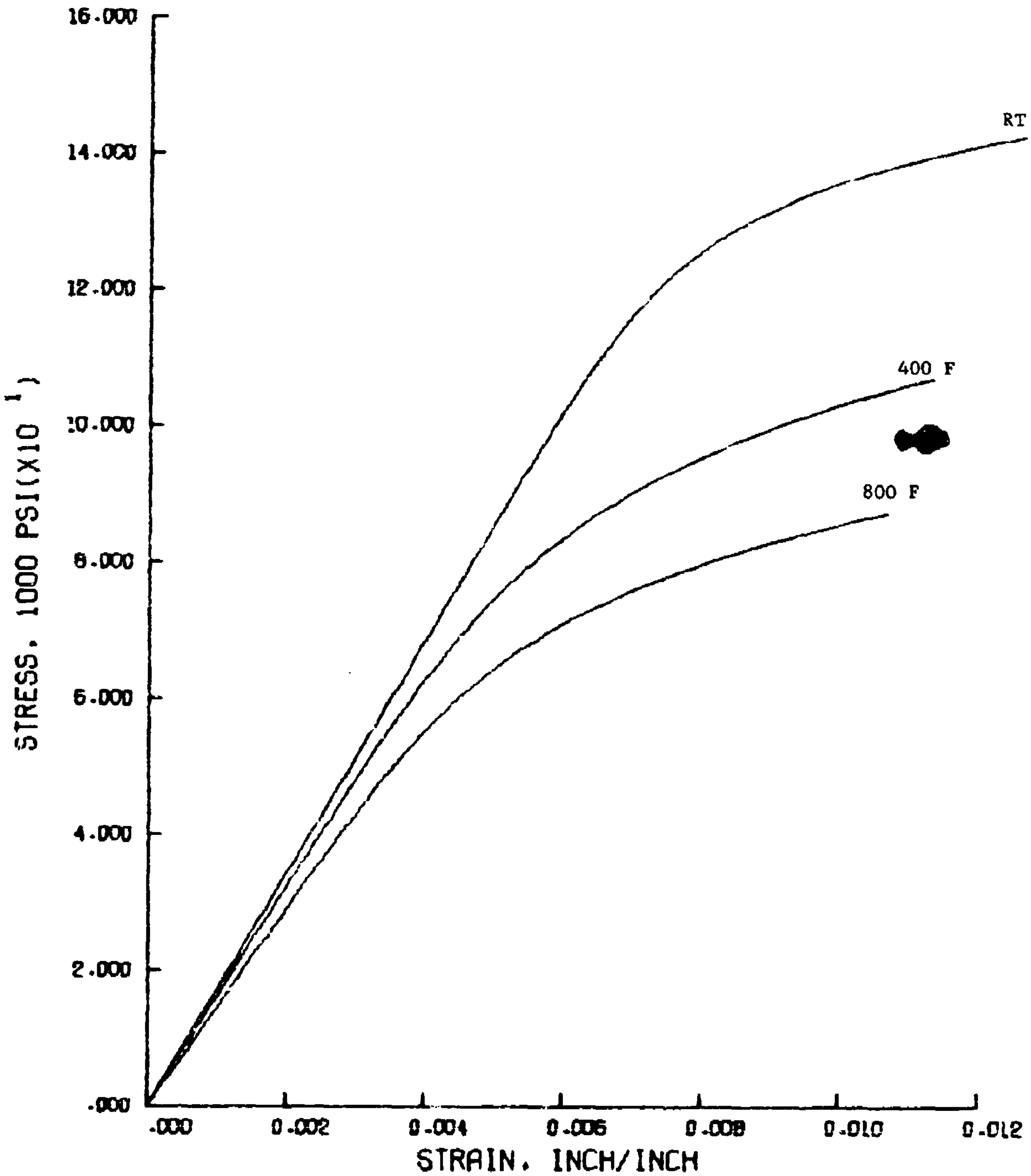

FIGURE 11. TYPICAL COMPRESSIVE STRESS-STRAIN CURVES AT TEMPERATURE FOR Ti-6Al-2Sn-4Zr-2Mo ALLOY CASTINGS

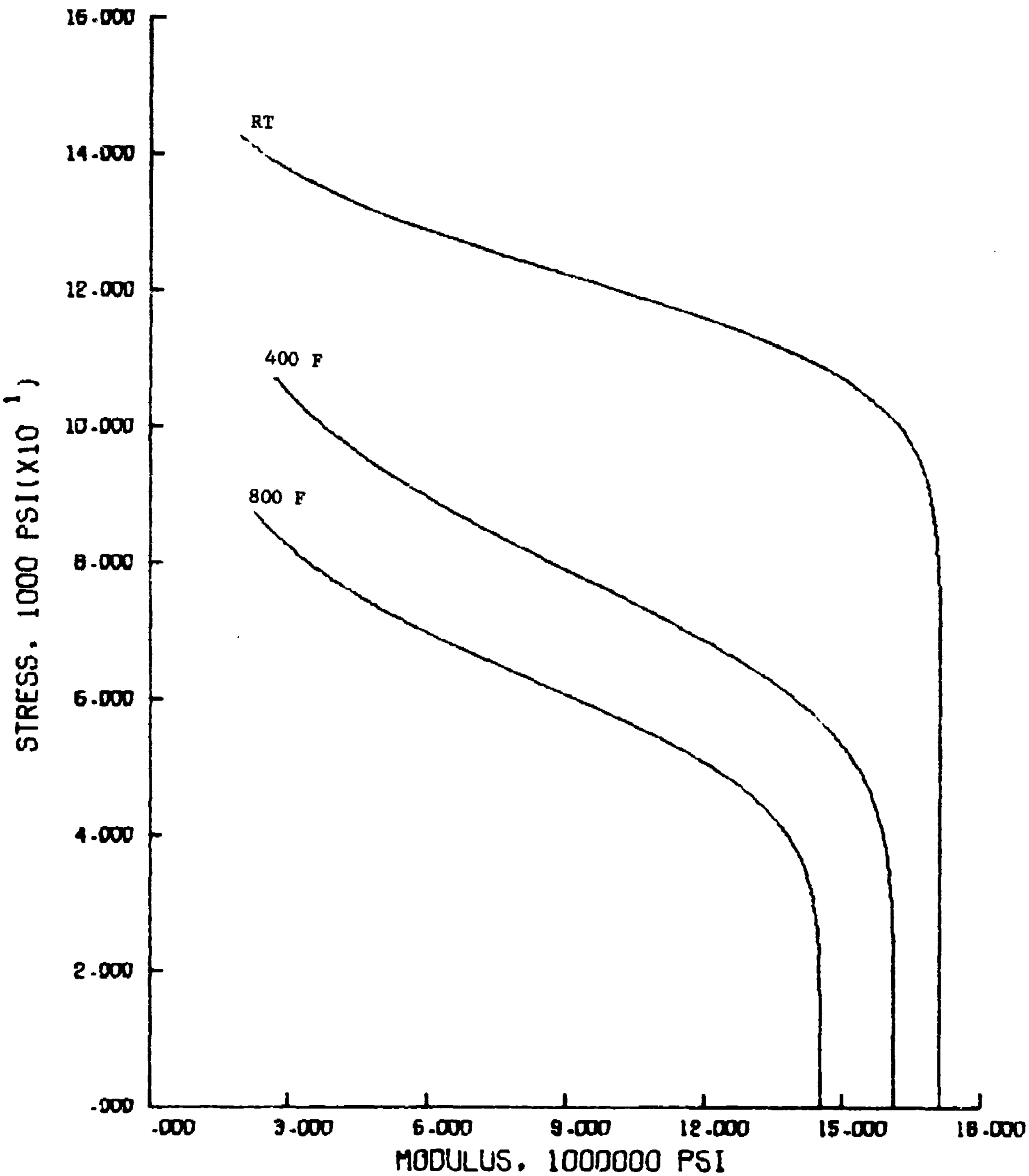

FIGURE 12. TYPICAL COMPRESSIVE TANGENT-MODULUS CURVES AT TEMPERATURE FOR Ti-6Al-2Sn-4Zr-2Mo ALLOY CASTINGS

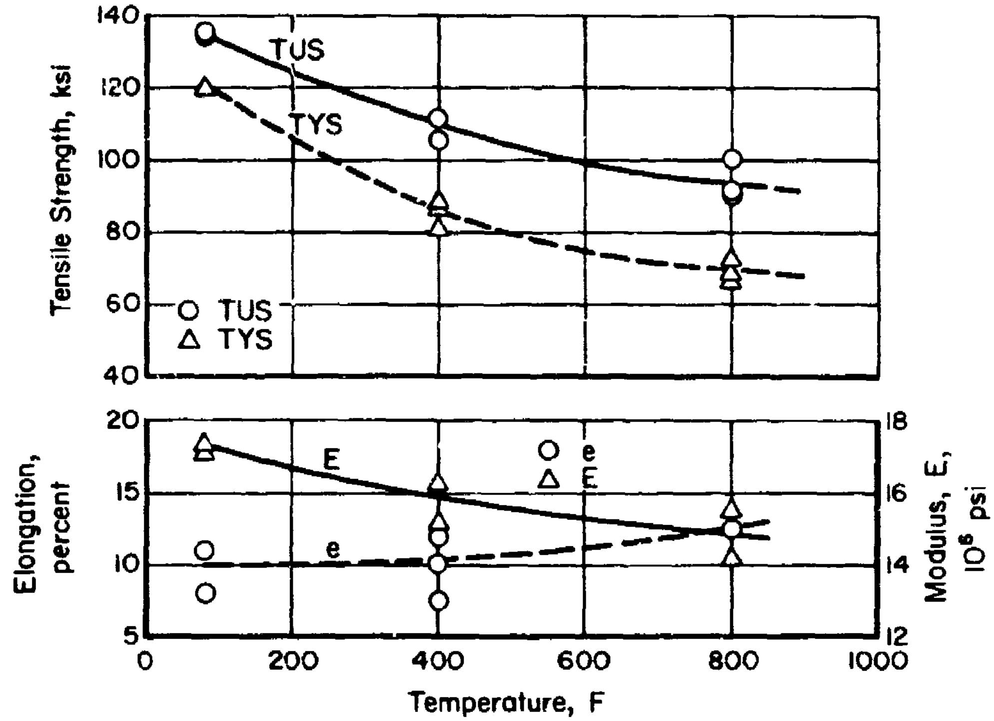

FIGURE 13. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF Ti-6Al-2Sn-4Zr-2Mo ALLOY CASTINGS

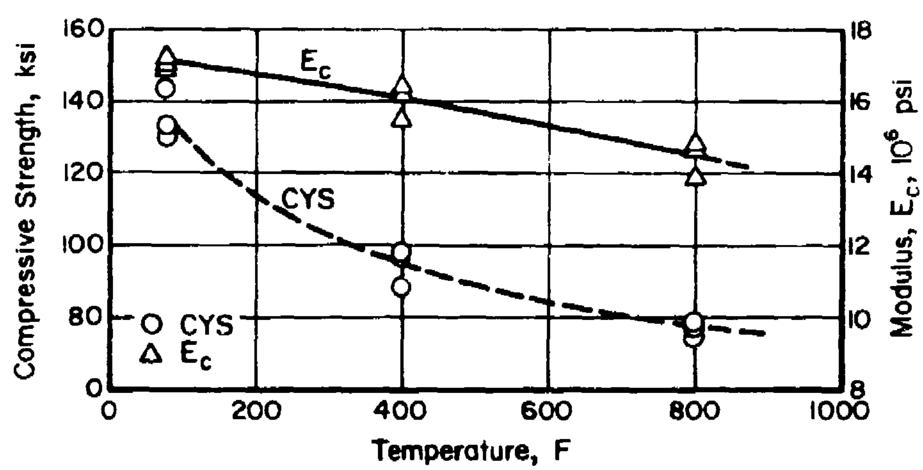

FIGURE 14. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF Ti-6Al-2Sn-4Zr-2Mo ALLOY CASTING

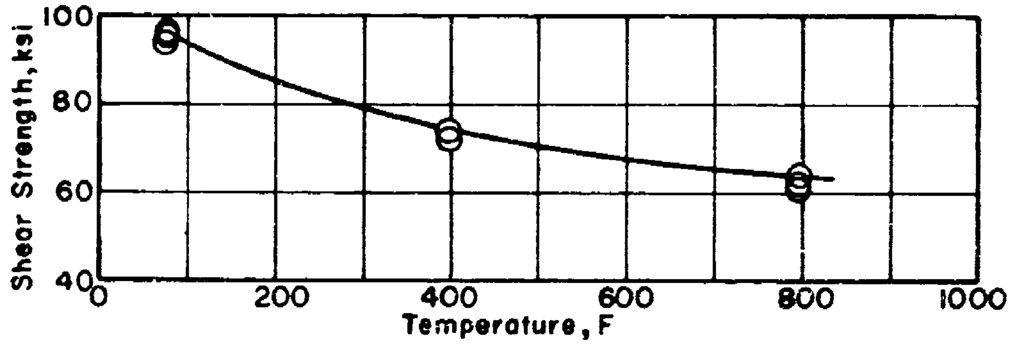

FIGURE 15. EFFECT OF TEMPERATURE ON THE SHEAR PROPERTIES OF Ti-6Al-2Sn-4Zr-2Mo ALLOY CASTING

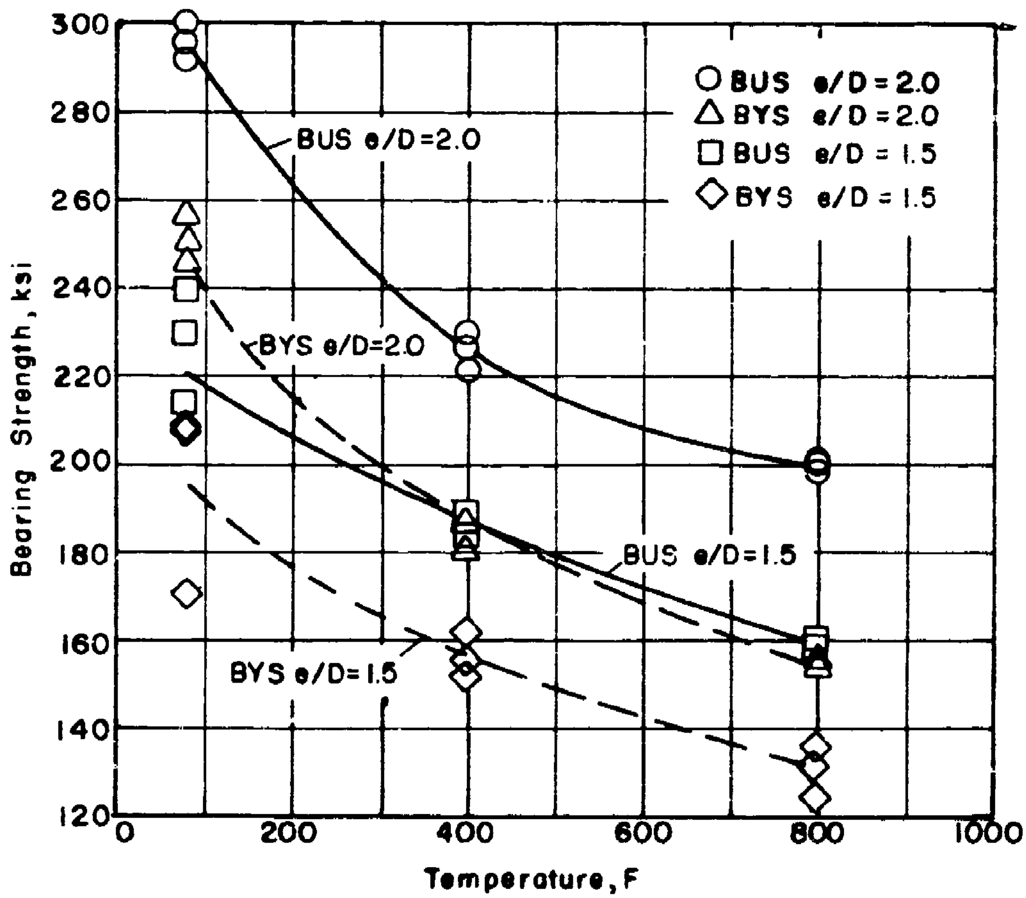

FIGURE 16. EFFECT OF TEMPERATURE ON THE BEARING PROPERTIES OF Ti-6Al-2Sn-4Zr-2Mo ALLOY CASTINGS

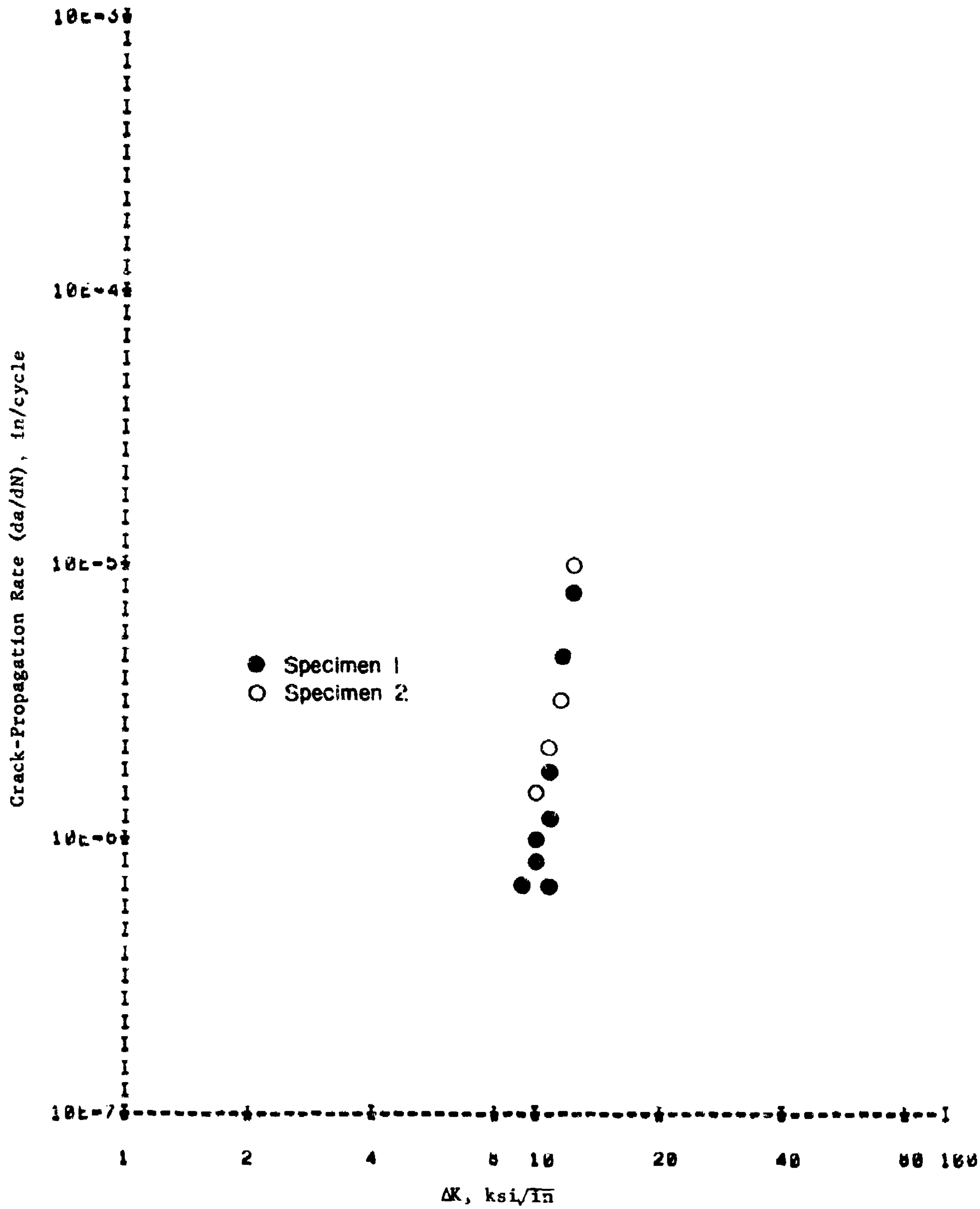

FIGURE 17. da/dN VERSUS ΔK for Ti-6Al-2Sn-4Zr-2Mo CASTINGS

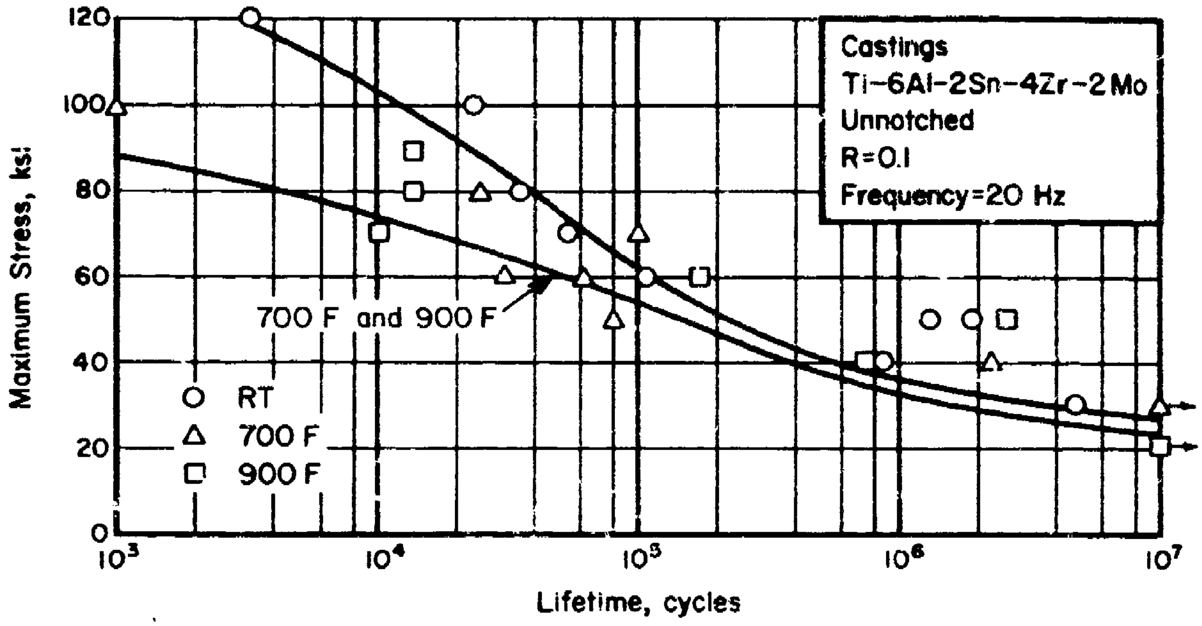

FIGURE 18. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED Ti-6Al-2Sn-4Zr-2Mo ALLOY CASTINGS

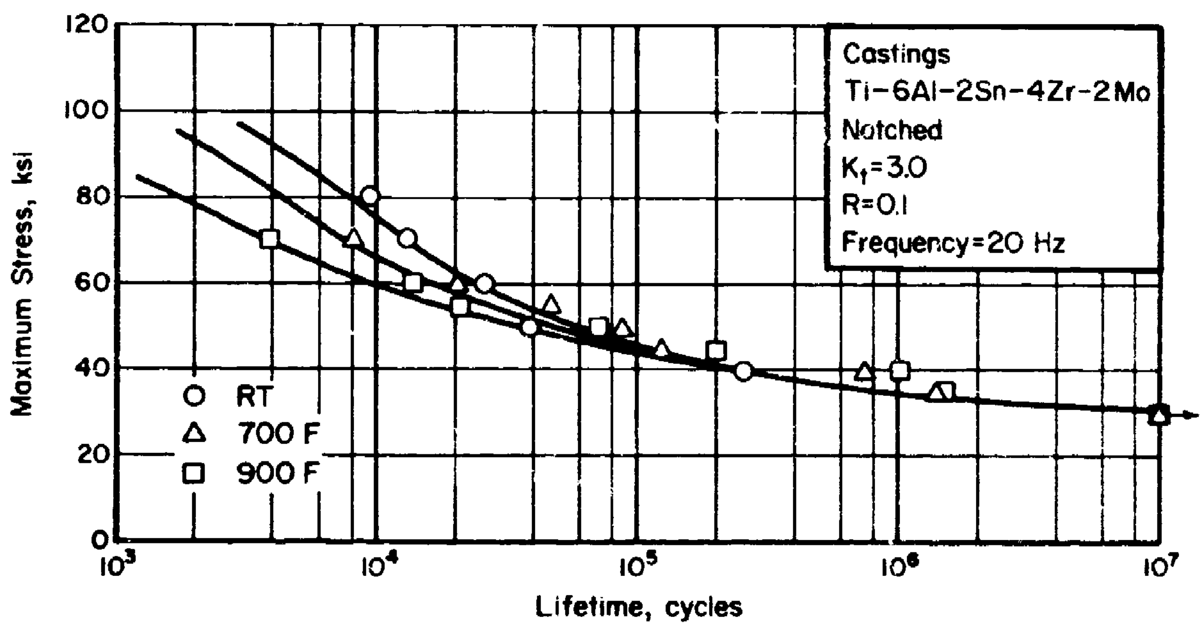

FIGURE 19. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) Ti-6Al-2Sn-4Zr-2Mo ALLOY CASTINGS

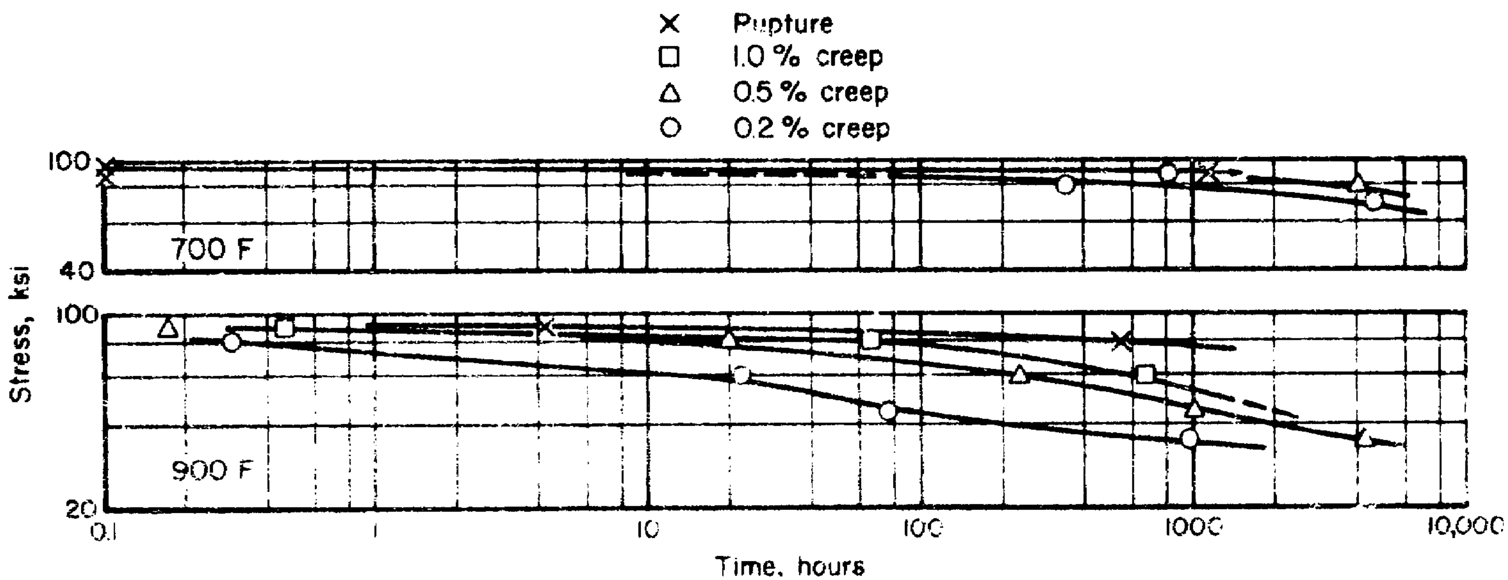

FIGURE 20. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR Ti-6Al-2Sn-4Zr-2Mo ALLOY CASTING

7175-T73511 Aluminum Alloy Extrusions

Material Description

This aluminum alloy is a development of Alcoa and is primarily a high purity modification of the 7075 alloy. It was developed to provide improvements in mechanical properties, fracture toughness, and stress corrosion resistance over 7075. The material evaluated on this program was an extrusion about 3/4-inch thick by 24-inches wide by 24-inches long supplied by the Air Force.

Composition limits for 7175 are as follows:

Chemical Composition	Percent
Si	0.15 max
Fe	0.20 max
Cu	1.2 to 2.0
Mn	0.10 max
Cr	0.18 to 0.30
Zn	5.1 to 6.1
Ti	0.10 max
Mg	2.1 to 2.9
Others (Each)	0.05 max
Others (Total)	0.15 max
Al	Balance

Processing and Heat Treating

The material was evaluated in the as-received -T73511 temper. Specimens were sectioned from the extrusion as shown in Figure 21.

Test Results

Tension. Results of tensile tests at room temperature, 250 F, and 350 F for longitudinal and transverse specimens are given in Table XVI. Typical stress-strain curves at temperature are presented in Figures 22 and 23. Effect-of-temperature curves are shown in Figure 28.

Compression. Results of compression tests at room temperature, 250 F, and 350 F for longitudinal and transverse specimens are shown in Table XVII. Typical stress-strain and tangent-modulus curves at temperature are presented in Figures 24 through 27. Effect-of-temperature curves are presented in Figure 29.

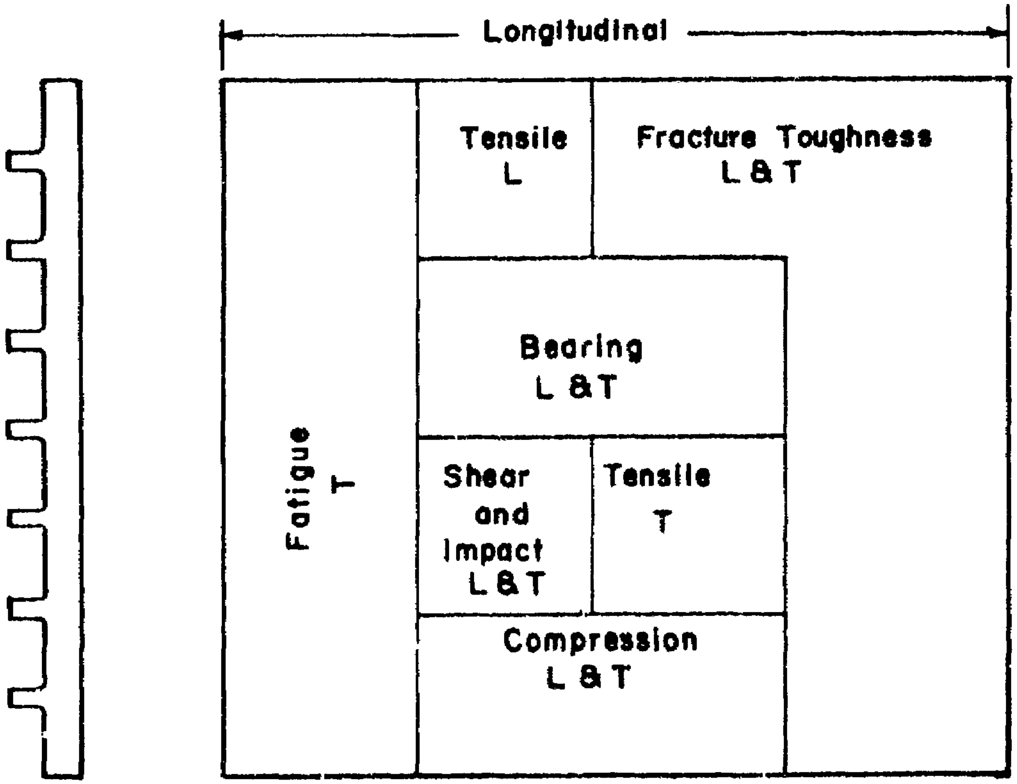

FIGURE 21. SPECIMEN AREA LAYOUT FOR 7175 EXTRUSION

Shear. Pin shear test results at room temperature, 250 F, and 350 F for longitudinal and transverse specimens are shown in Table XVIII. Effect-of-temperature curves are presented in Figure 30.

Bearing. Results of bearing tests at $e/D = 1.5$ and $e/D = 2.0$ for longitudinal and transverse specimens at room temperature, 250 F, and 350 F are given in Table XIX. Effect-of-temperature curves are presented in Figure 31.

Impact. Results of Charpy impact tests for longitudinal and transverse specimens at room temperature are given in Table XX.

Fracture Toughness. Results of compact-tension-type fracture toughness tests for longitudinal and transverse specimens are presented in Table XXI. Candidate K_Q values are considered valid K_{Ic} values per ASTM E399.

Fatigue. Results of axial-load tests for unnotched and notched transverse specimens at room temperature, 250 F, and 350 F are given in Tables XXII and XXIII. S-N curves are shown in Figures 32 and 33.

Creep and Stress-Rupture. No tests were conducted for this aluminum alloy.

Stress Corrosion. Tests were conducted as described in the experimental procedures section of this report. No cracks or failure occurred in the test duration.

Thermal Expansion. The coefficient of thermal expansion for this alloy is 12.5×10^{-6} in/in/F (70 - 212 F).

Density. Density for this material is 0.101 lb/in^3.

TABLE XVI. RESULTS OF TENSILE TESTS FOR 7175-T73511 ALUMINUM ALLOY EXTRUSIONS

Specimen Number		Tensile Ultimate Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 1 Inch, percent	Reduction in Area, percent	Tensile Modulus, 10^3 ksi
			Longitudinal at Room Temperature			
1L-1		77.0	65.9	13.0	35.9	10.7
1L-2		77.0	66.3	13.0	35.9	10.5
1L-3		77.2	66.7	12.5	34.6	10.3
	Average	77.1	66.3	12.8	35.5	10.5
			Transverse at Room Temperature			
1T-1		76.4	64.6	13.0	29.6	10.7
1T-2		74.6	62.9	12.0	19.1	11.5
1T-3		78.0	67.1	11.0	34.2	10.7
	Average	76.3	64.9	12.0	27.6	10.9
			Longitudinal at 250 F			
1L-4		63.3	60.3	23.0	50.2	9.6
1L-5		62.7	60.1	21.0	50.1	10.7
1L-6		62.4	60.2	20.5	52.5	10.0
	Average	62.8	60.2	21.5	50.9	10.1
			Transverse at 250 F			
1T-4		59.1	55.7	16.0	37.6	10.3
1T-5		62.6	60.3	20.0	48.4	10.7
1T-6		62.4	60.2	23.0	49.1	10.8
	Average	61.4	58.7	19.7	45.0	10.6
			Longitudinal at 350 F			
1L-7		45.4	39.9	28.0	69.2	8.5
1L-8		48.2	41.2	30.0	69.5	8.5
1L-9		46.4	42.0	29.6	69.3	8.0
	Average	46.8	41.0	29.2	69.4	8.3
			Transverse at 350 F			
1T-7		46.5	37.9	27.0	53.6	8.5
1T-8		46.0	37.0	27.0	50.8	8.7
1T-9		46.0	39.2	26.0	51.9	8.6
	Average	46.2	38.0	26.7	52.1	8.6

TABLE XVII. RESULTS OF COMPRESSION TESTS FOR 7175-T73511 ALUMINUM ALLOY EXTRUSIONS

Specimen Number		0.2 Percent Offset Yield Strength, ksi	Compressive Modulus, 10^3 ksi
		Room Temperature (Longitudinal)	
2L-1		69.8	10.0
2L-2		69.9	9.9
2L-3		69.8	10.4
	Average	69.8	10.1
		Room Temperature (Transverse)	
2T-1		70.4	10.7
2T-2		70.3	10.5
2T-3		70.2	10.2
	Average	70.3	10.5
		250 F (Longitudinal)	
2L-4		61.3	10.1
2L-5		63.6	9.7
2L-6		62.7	10.6
	Average	62.5	10.1
		250 F (Transverse)	
2T-4		62.2	10.1
2T-5		60.9	10.2
2T-6		63.7	9.6
	Average	62.3	10.0
		350 F (Longitudinal)	
2L-7		50.8	9.4
2L-8		49.9	9.8
2L-9		50.0	9.5
	Average	50.2	9.6
		350 F (Transverse)	
2T-7		49.0	9.7
2T-8		51.4	9.4
2T-9		52.1	9.6
	Average	50.8	9.5

TABLE XVIII. RESULTS OF PIN SHEAR TESTS FOR 7175-T73511 ALUMINUM ALLOY EXTRUSIONS

Specimen Number		Shear Ultimate Strength, ksi
	Longitudinal at Room Temperature	
4L-1		46.7
4L-2		46.2
4L-3		46.2
	Average	46.4
	Transverse at Room Temperature	
4T-1		45.8
4T-2		47.0
4T-3		46.8
	Average	46.5
	Longitudinal at 250 F	
4L-4		39.2
4L-5		39.5
4L-6		38.1
	Average	38.9
	Transverse at 250 F	
4T-4		38.4
· T-5		39.1
4T-6		38.4
	Average	38.6
	Longitudinal at 350 F	
4L-7		31.4
4L-8		31.7
4L-9		31.5
	Average	31.5
	Transverse at 350 F	
4T-7		30.9
4T-8		31.5
4T-9		31.4
	Average	31.3

TABLE XIX. RESULTS OF BEARING TESTS OF e/D = 1.5 AND 2.0 FOR 7175-T73511 ALUMINUM ALLOY EXTRUSIONS

Specimen Number	Specimen Orientation		Bearing Ultimate Strength, ksi		Bearing Yield Strength, ksi	
			e/D = 1.5	e/D = 2.0	e/D = 1.5	e/D = 2.0
			Room Temperature			
L-1	L		116.1	154.7	91.0	109.1
L-2	L		118.3	156.2	92.9	111.1
L-3	L		115.7	159.0	90.6	114.9
		Average	116.7	156.6	91.5	111.7
T-1	T		118.3	153.5	94.6	112.0
T-2	T		120.5	153.5	96.6	113.0
T-3	T		119.6	158.5	98.6	117.2
		Average	119.5	155.2	96.6	114.1
			250 F			
L-13	L		102.3	125.4	90.7	94.8
L-14	L		102.2	128.0	90.2	94.6
L-15	L		99.0	126.0	86.0	95.6
		Average	101.2	126.5	89.0	95.0
T-13	T		100.9	127.1	84.8	104.4
T-14	T		97.1	121.0	83.3	96.0
T-15	T		96.4	124.6	81.2	100.7
		Average	98.1	124.2	83.0	100.4
			350 F			
L-16	L		75.6	(a)	68.[illegible]	(a)
L-17	L		77.8	87.5	69.9	73.6
L-18	L		75.6	93.6	66.5	78.9
		Average	76.3	90.5	68.3	76.2
T-16	T		78.9	84.6	70.8	76.9
T-17	T		74.6	98.3	69.6	85.4
T-18	T		75.6	98.3	[illegible]	87.6
		Average	76.4	93.7	[illegible].7	83.3

(a) Specimen overheated.

TABLE XX. RESULTS OF CHARPY IMPACT TESTS AT ROOM TEMPERATURE FOR 7175-T73511 ALUMINUM ALLOY EXTRUSIONS

Specimen Number		Energy, ft/lbs
10L-1		5.5
10L-2		7.0
10L-3		6.0
	Average	6.2
10T-1		3.5
10T-2		3.5
10T-3		3.0
	Average	3.3

TABLE XXI. RESULTS OF COMPACT TENSION FRACTURE TOUGHNESS TESTS FOR 7175-T73511 ALUMINUM ALLOY EXTRUSION

Specimen Number	W, inches	B, inches	a, inches	P_Q, lbs.	P_{max}, lbs.	f(a/w)	K_Q
			Longitudinal (L-T)				
6L-1	2.0	1.0	1.020	3700	3800	9.90	25.9
6L-2	2.0	1.0	1.022	3775	3775	9.90	26.4
6L-3	2.0	1.0	1.001	3900	3900	9.60	26.4
						Average	26.2
			Transverse (T-L)				
6T-1	2.0	1.0	1.002	4650	5000	9.60	31.5
6T-2	2.0	1.0	.986	4950	4950	9.41	32.6
6T-3	2.0	1.0	.993	4800	4800	9.50	32.2
						Average	32.1

TABLE XXII. RESULTS OF AXIAL LOAD FATIGUE TESTS FOR UNNOTCHED 7175-T73511 ALUMINUM ALLOY EXTRUSION AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	Cycles to Failure
	Room Temperature	
5-2	60	28,300
5-5	55	37,800
5-3	50	65,200
5-27	47.5	381,300
5-7	47.5	774,400
5-4	45	4,672,000
5-6	42.5	10,000,000 (a)
5-1	40	10,000,000 (a)
	250 F	
5-16	60	23,300
5-15	55	31,800
5-8	50	21,700 (b)
5-9	50	56,600 (b)
5-10	50	31,400
5-11	45	78,900
5-12	40	148,200
5-13	35	207,200
5-14	30	10,000,000 (a)
	350 F	
5-22	55	(c)
5-17	50	7,300
5-18	45	12,900
5-19	40	25,500
5-23	37.5	216,800
5-20	35	589,400
5-24	32.5	551,100
5-25	30	1,812,600
5-26	27.5	5,316,000
5-28	25	10,000,000 (a)

(a) Did not fail.

(b) Failed in grip.

(c) Failed on first cycle.

TABLE XXIII. RESULTS OF AXIAL LOAD FATIGUE TESTS FOR NOTCHED (K_t = 3.0) 7175-T73511 ALUMINUM ALLOY EXTRUSIONS AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	Cycles to Failure
	Room Temperature	
5-34	40	6,700
5-33	35	9,900
5-31	30	56,100
5-39	30	17,900
5-35	25	47,000
5-37	25	45,100
5-32	20	93,300
5-38	17.5	133,200
5-36	15	10,000,000 (a)
	250 F	
5-47	40	5,700
5-45	35	9,800
5-42	30	17,100
5-46	25	32,700
5-40	25	64,800
5-43	20	72,100
5-48	17.5	158,500
5-41	15	241,900
5-44	10	10,000,000 (a)
	350 F	
5-52	35	6,400
5-53	30	12,100
5-49	25	23,800
5-54	20	40,000
5-50	15	130,200
5-55	12.5	327,400
5-51	10	8,479,800 (b)
5-56	10	10,000,000 (a)

(a) Did not fail.

(b) Failed in grip.

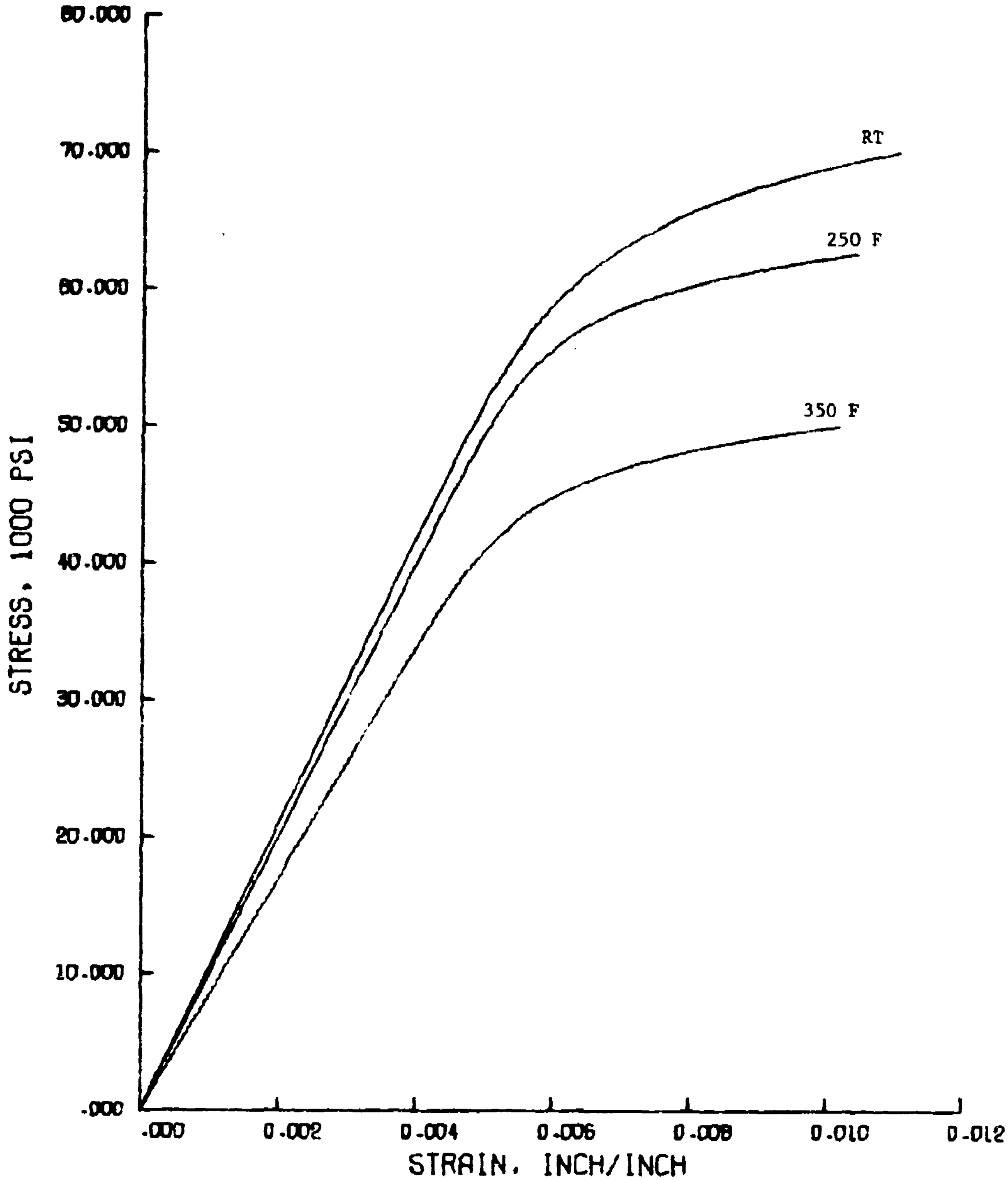

FIGURE 22. TYPICAL TENSILE LONGITUDINAL STRESS-STRAIN CURVES AT TEMPERATURE FOR 7175-T73511 ALUMINUM ALLOY EXTRUSIONS

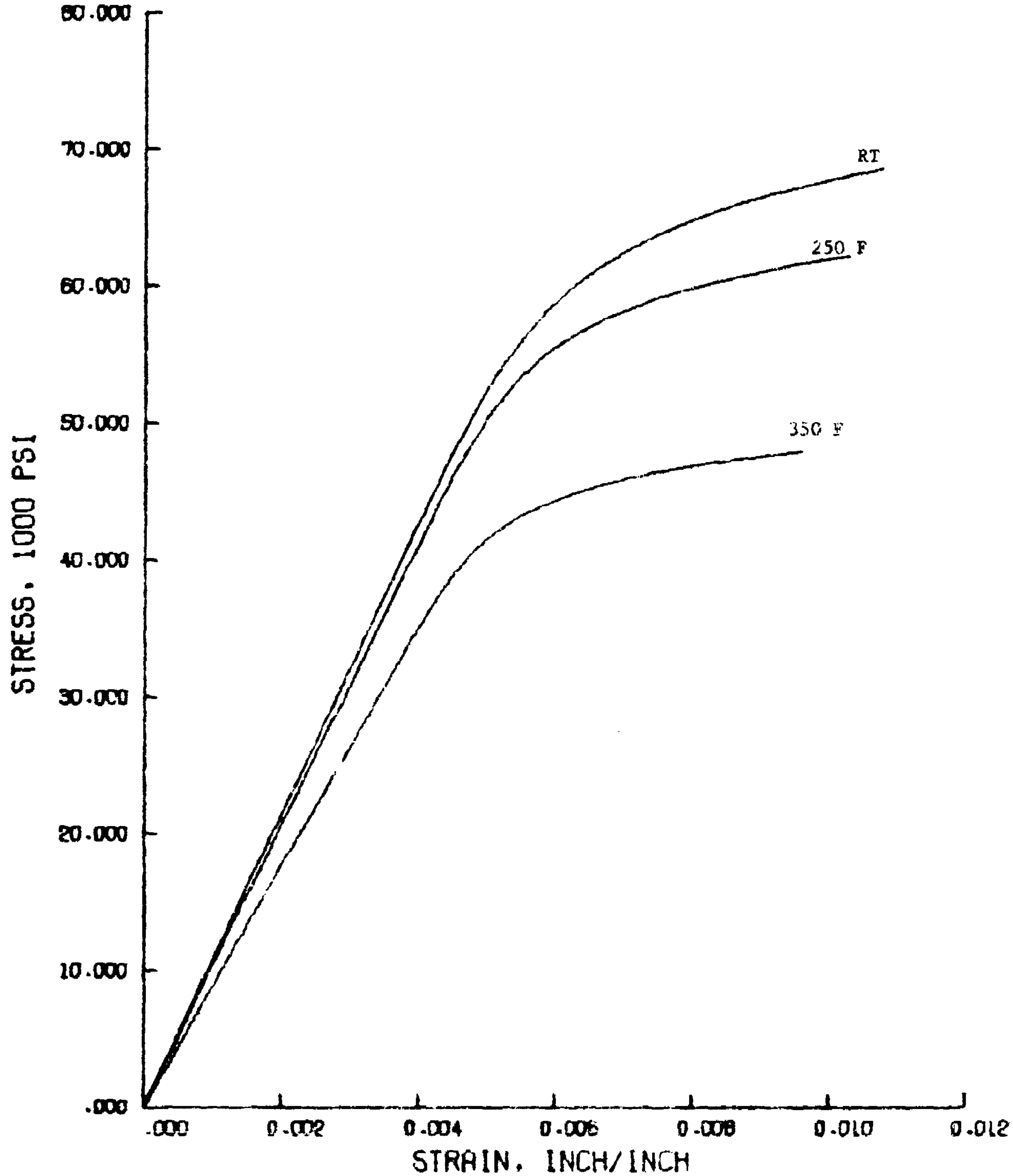

FIGURE 23. TYPICAL TENSILE TRANSVERSE STRESS-STRAIN CURVES AT TEMPERATURE FOR 7175-T73511 ALUMINUM ALLOY EXTRUSIONS

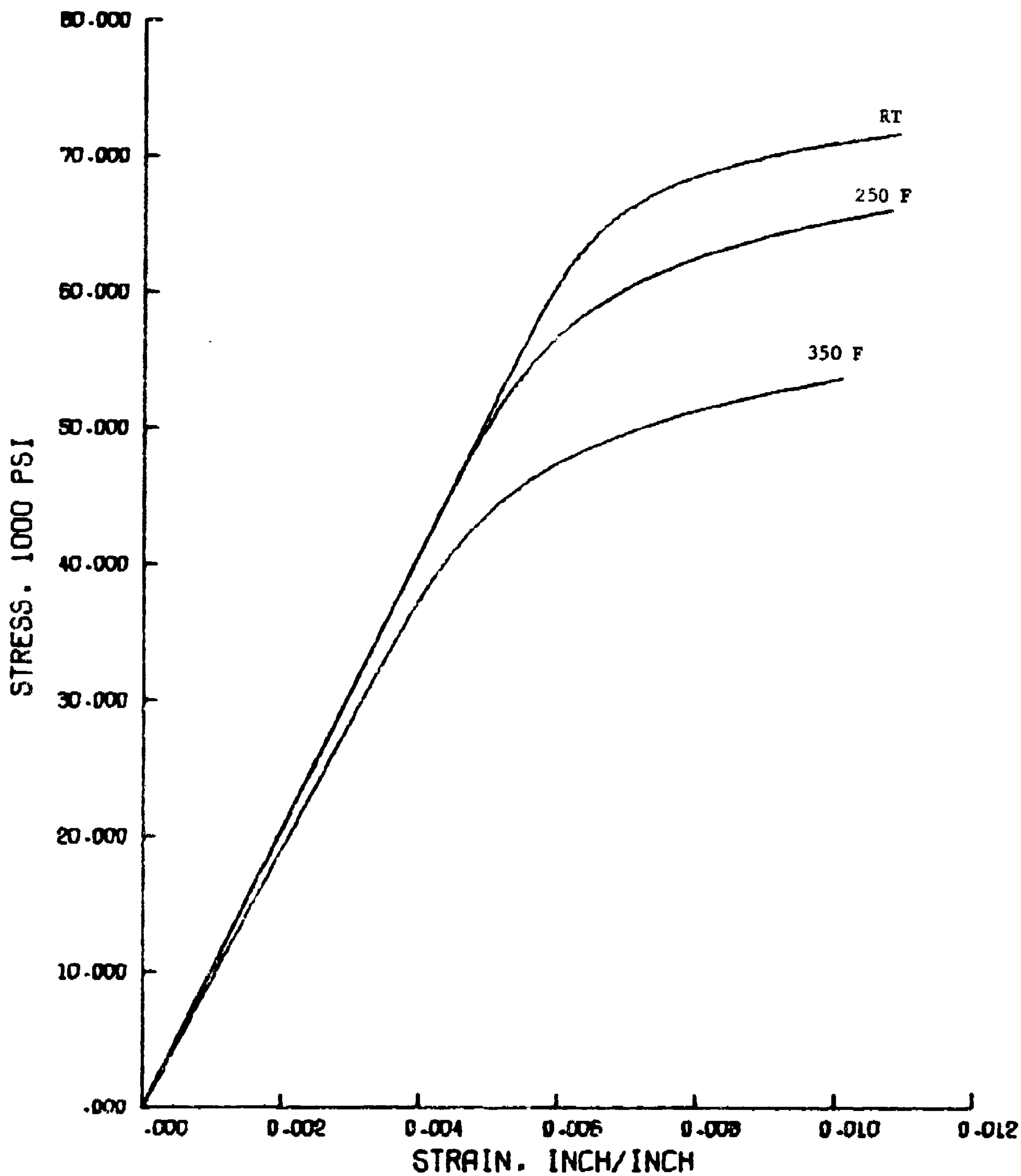

FIGURE 24. TYPICAL COMPRESSIVE LONGITUDINAL STRESS-STRAIN CURVES AT TEMPERATURE FOR 7175-T73511 ALUMINUM ALLOY EXTRUSIONS

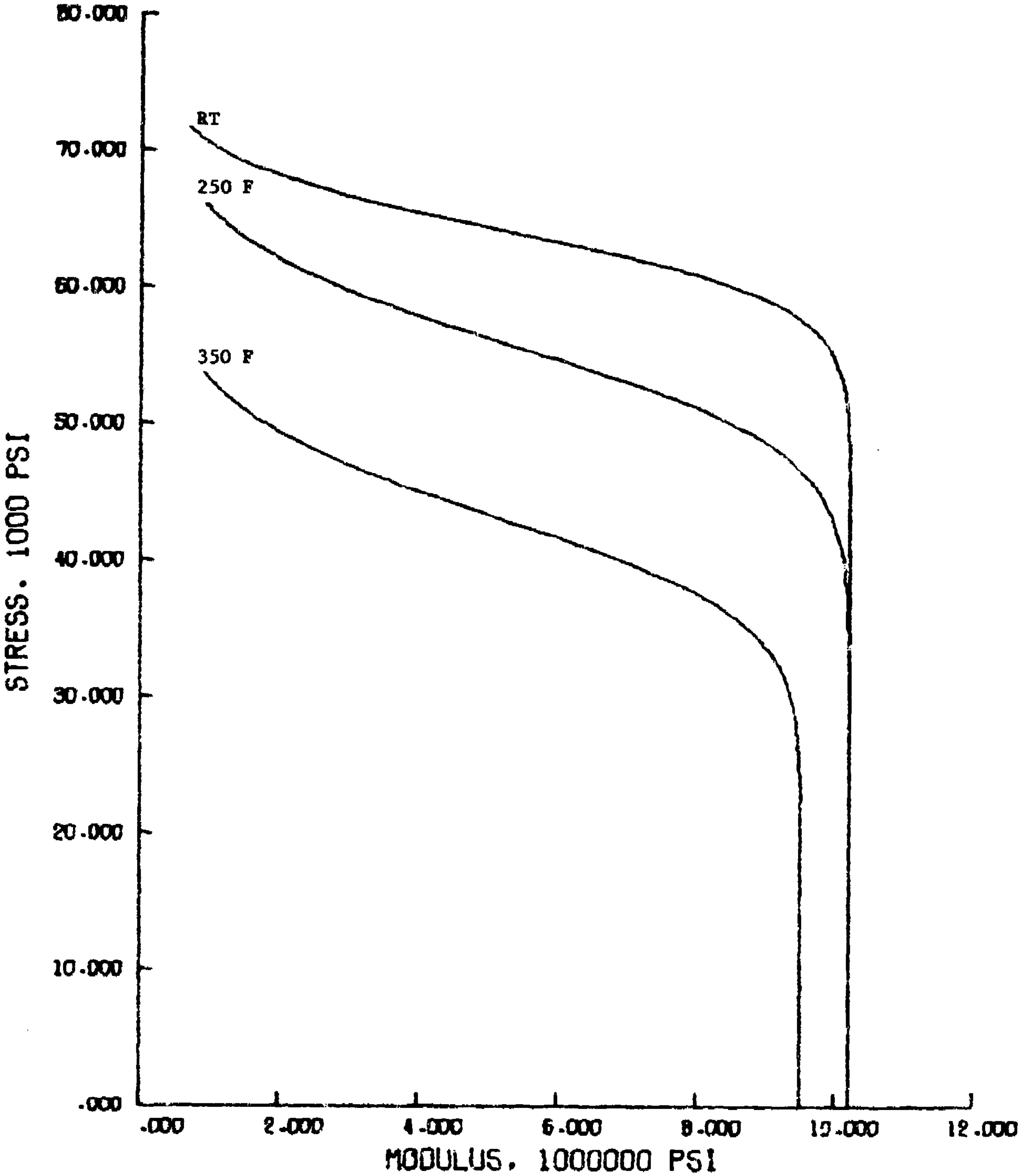

FIGURE 25. TYPICAL COMPRESSIVE LONGITUDINAL TANGENT-MODULUS CURVES AT TEMPERATURE FOR 7175-T73511 ALUMINUM ALLOY EXTRUSIONS

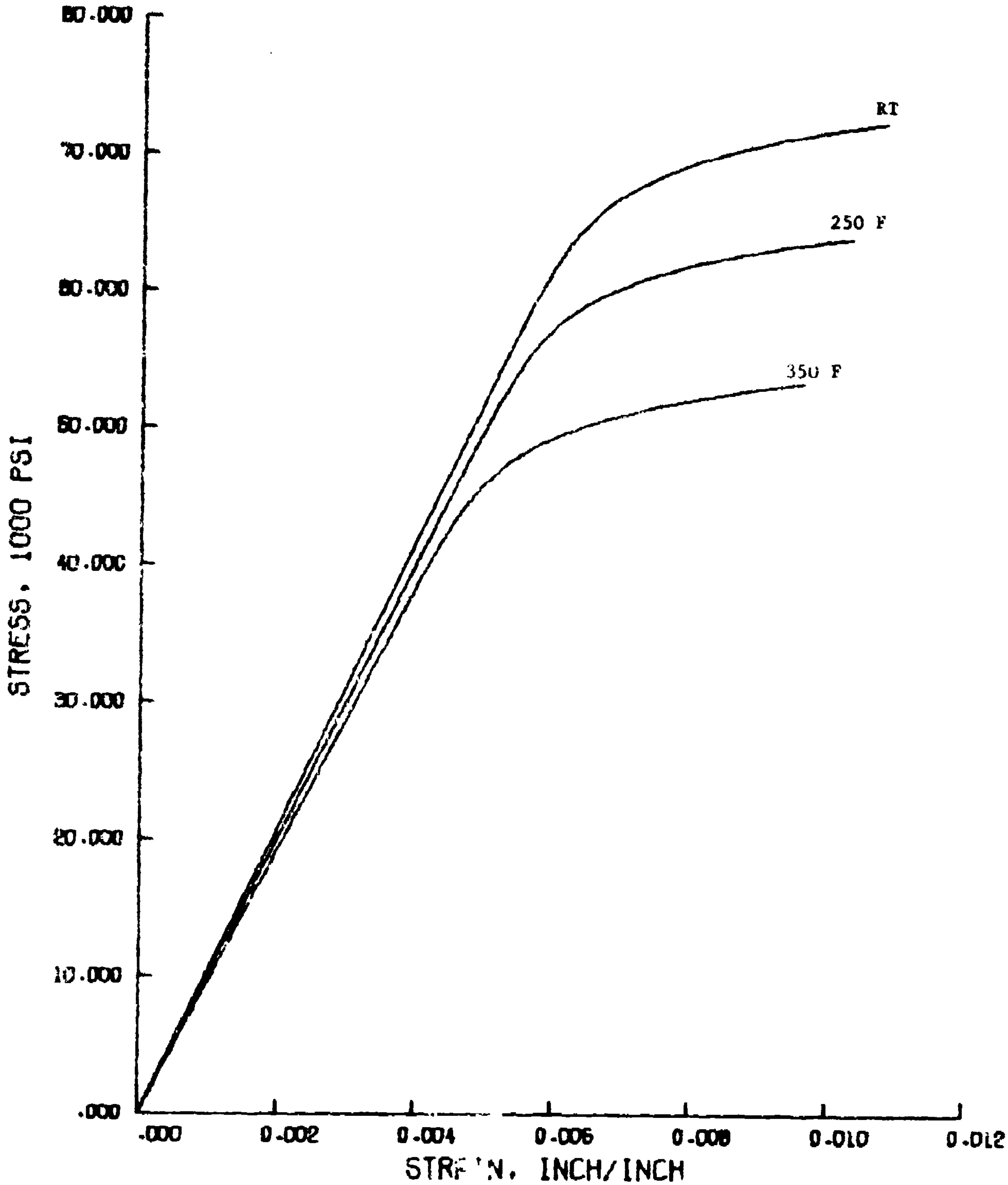

FIGURE 26. TYPICAL COMPRESSIVE TRANSVERSE STRESS-STRAIN CURVES AT TEMPERATURE FOR 7175-T73511 ALUMINUM ALLOY EXTRUSIONS

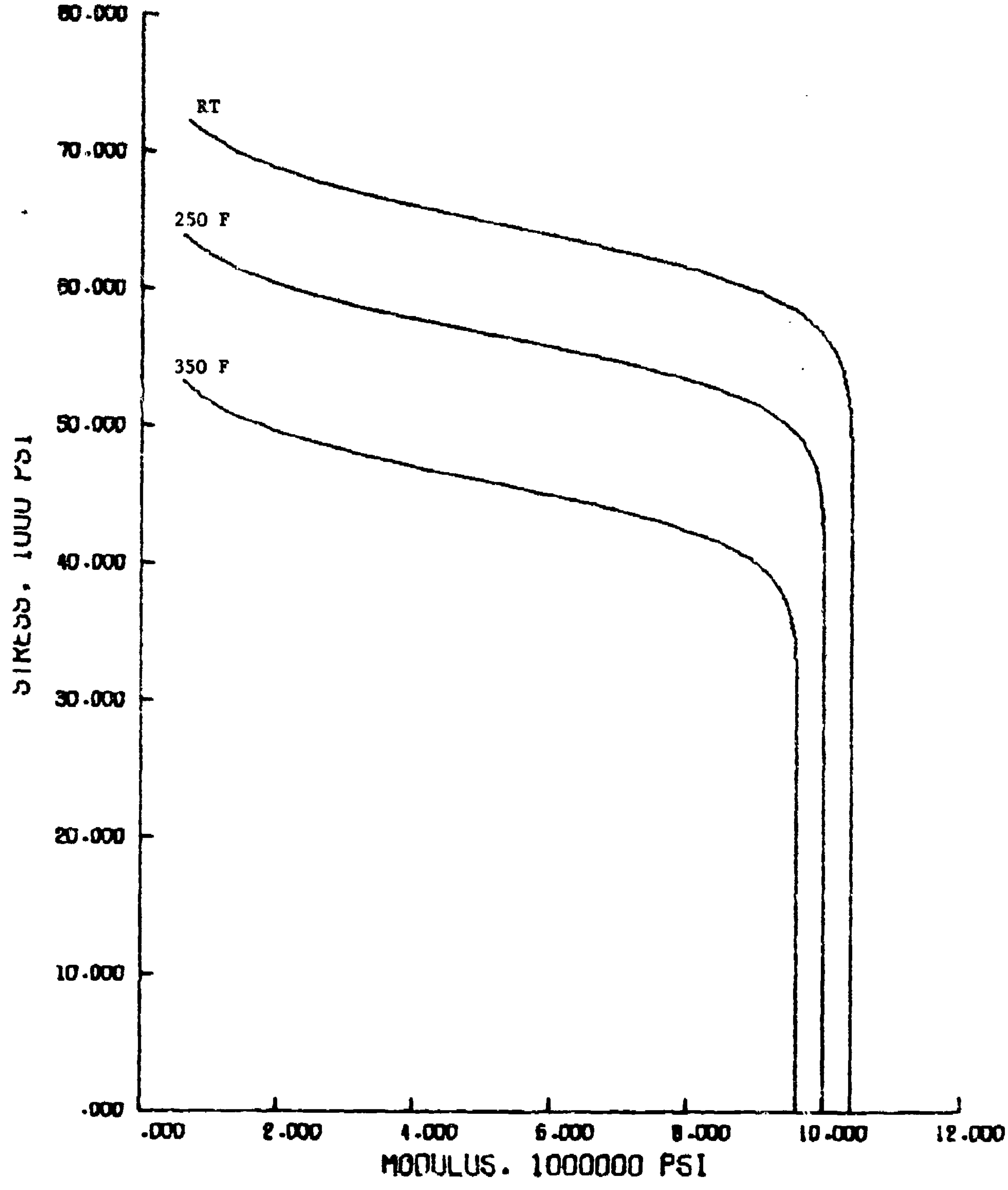

FIGURE 27. TYPICAL COMPRESSIVE TRANSVERSE TANGENT-MODULUS CURVES AT TEMPERATURE FOR 7175-T73511 ALUMINUM ALLOY EXTRUSIONS

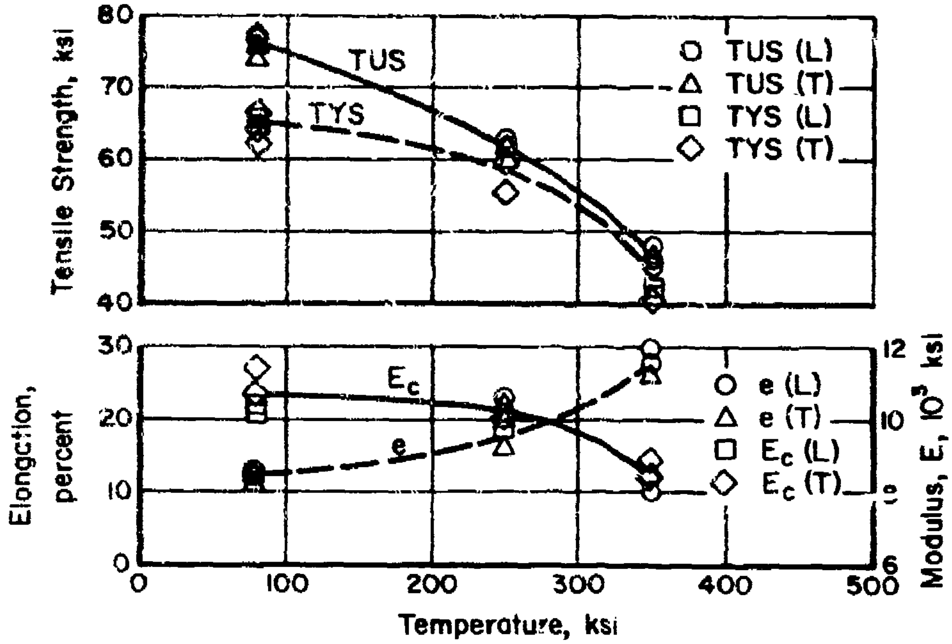

FIGURE 28. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 7175-T73511 ALUMINUM ALLOY EXTRUSIONS

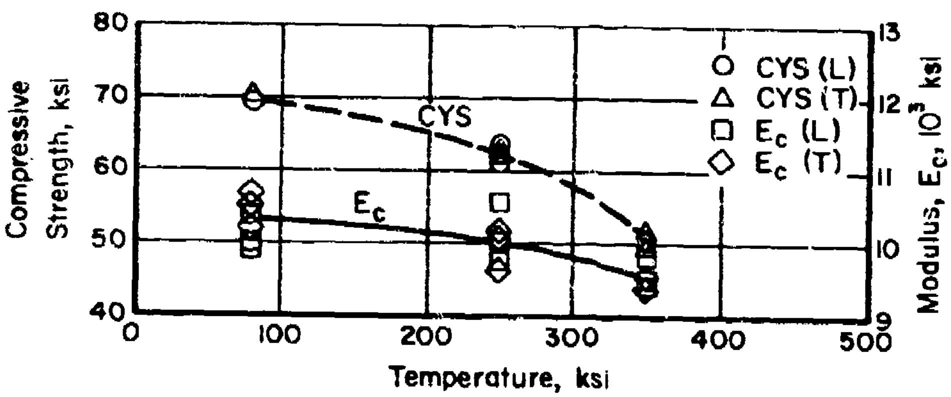

FIGURE 29. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 7175-T73511 ALUMINUM ALLOY EXTRUSIONS

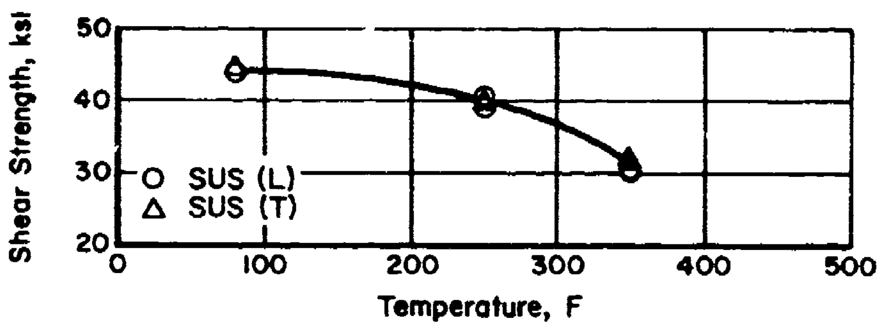

FIGURE 30. EFFECT OF TEMPERATURE ON THE SHEAR PROPERTIES OF 7175-T73511 ALUMINUM ALLOY EXTRUSIONS

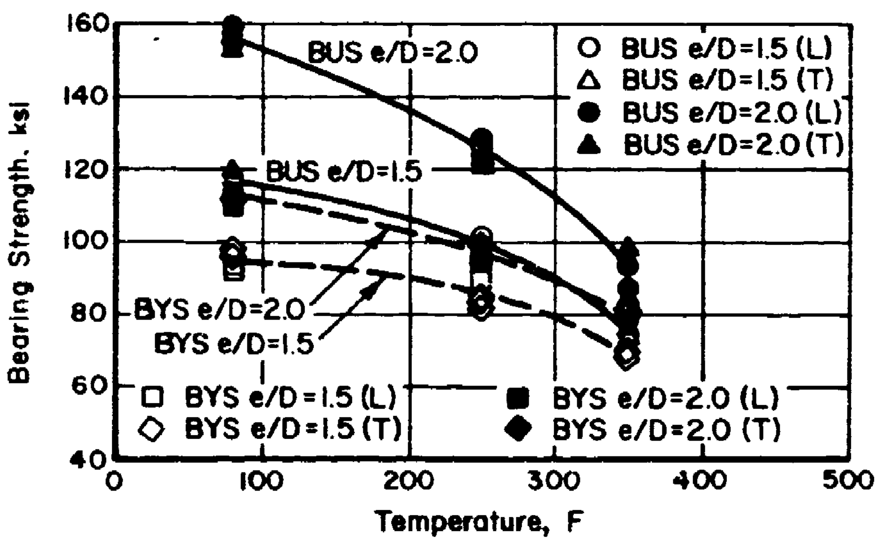

FIGURE 31. EFFECT OF TEMPERATURE ON THE BEARING PROPERTIES OF 7175-T73511 ALUMINUM ALLOY EXTRUSIONS

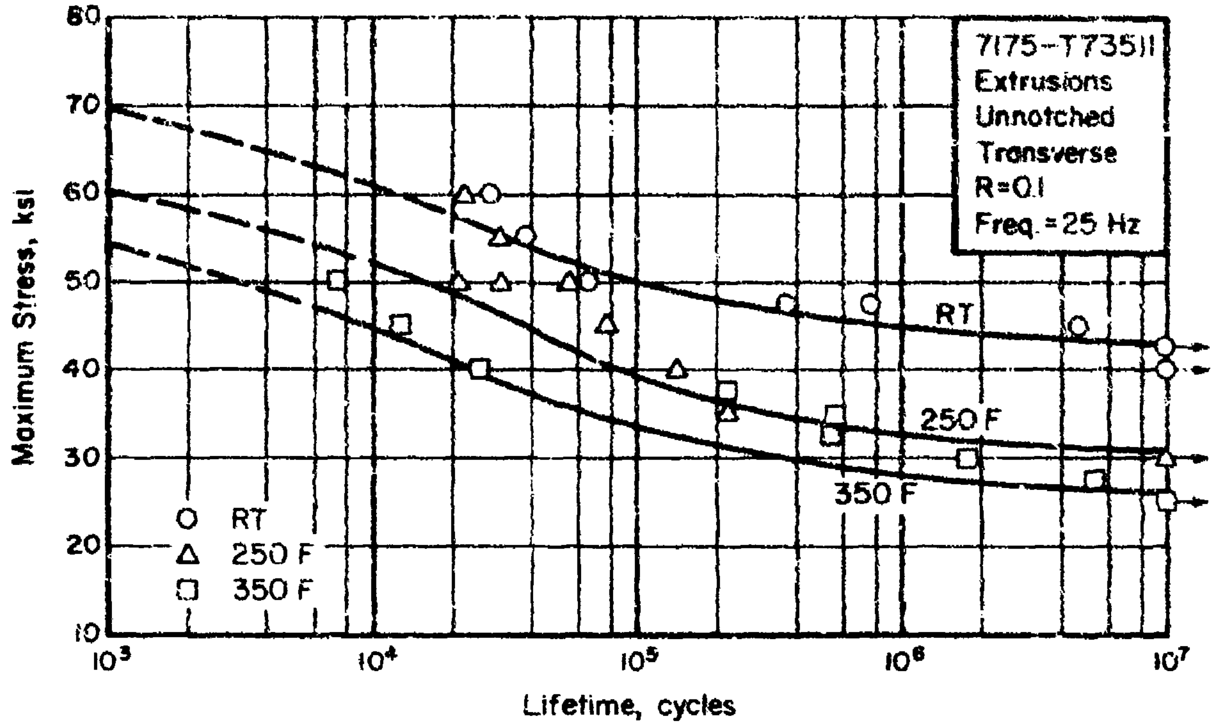

FIGURE 32. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED 7175-T73511 ALUMINUM ALLOY EXTRUSIONS

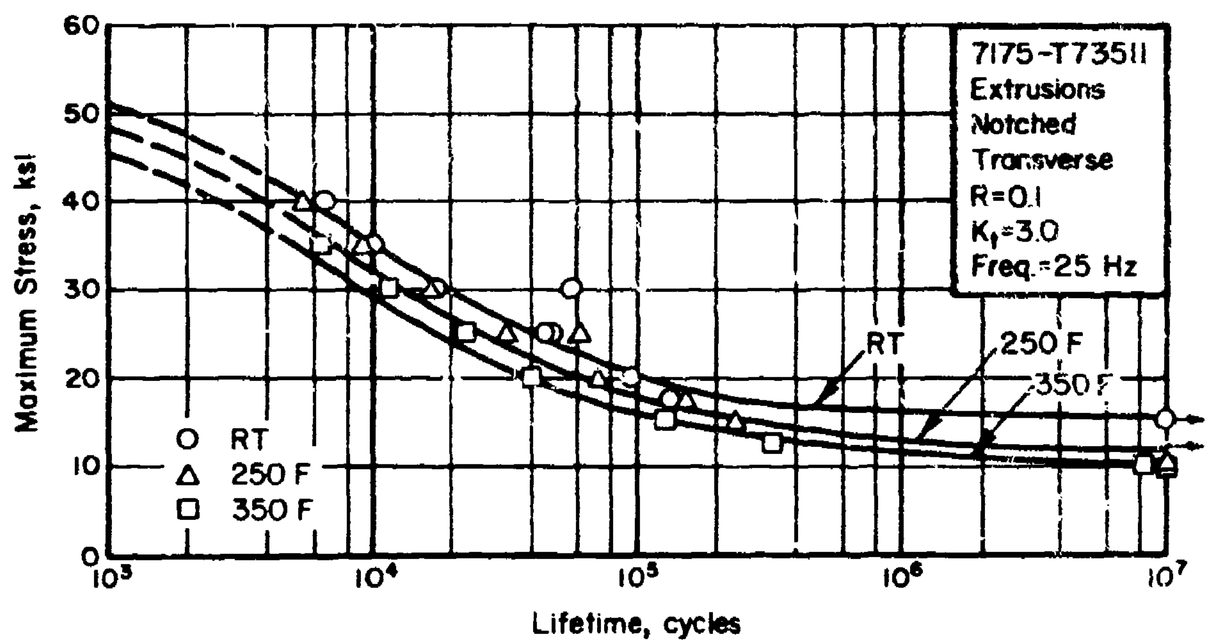

FIGURE 33. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) 7175-T73511 ALUMINUM ALLOY EXTRUSIONS

Ti-6Al-4V PM Product

Material Description

The material used for this evaluation was Ti-6Al-4V pressed and vacuum sintered to 94 percent minimum density. It was supplied by Dynamet Technology and produced as part of current manufacturing production for a major airframe manufacturer. Since the material was part of a production run for various parts, it varied in cross section and length from 2 inches x 1 inch x 6 inches to smaller sizes.

Processing and Heat Treating

The material was evaluated in the as-received condition as described above. Specimens were selected from various section sizes of the total of 90 inches (12 pieces) of material.

Test Results

Tension. Results of tensile tests at room temperature, 400 F, and 800 F are shown in Table XXIV. Typical stress-strain curves at temperature are presented in Figure 34. Effect-of-temperature curves are shown in Figure 37.

Compression. Compression test results at room temperature, 400 F. and 800 F are given in Table XXV. Typical stress-strain and tangent-modulus curves at temperature are presented in Figures 35 and 36. Effect-of-temperature curves are shown in Figure 38.

Shear. Results of pin type shear tests at room temperature, 400 F, and 800 F are shown in Table XXVI. Effect-of-temperature curves are presented in Figure 39.

Bearing. Results of bearing tests at e/D = 1.5 and e/D = 2.0 at room temperature, 400 F, and 800 F are given in Table XXVII. Effect-of-temperature curves are presented in Figure 40.

Impact. Results of Charpy impact tests at room temperature are given in Table XXVIII.

Fracture Toughness. Compact tension fracture toughness tests were conducted at room temperature. Due to the material size restrictions, valid K_{Ic} values were not obtained.

Fatigue. Results of axial load tests for unnotched and notched specimens at room temperature, 400 F, and 800 F are shown in Tables XXIX and XXX. S-N curves are presented in Figures 41 and 42.

Stress Corrosion. Tests were conducted as described in the experimental procedures section of this report. Some minor cracking but no failures occurred in the test duration.

Thermal Expansion. The coefficient of thermal expansion for this material is 6.2×10^{-6} in/in/F (70 - 800 F).

Density. The density of this material is 0.151 lb/in^3.

TABLE XXIV. RESULTS OF TENSILE TESTS FOR Ti-6Al-4V POWDER METALLURGY PRODUCT

Specimen Number	Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 1 Inch, percent	Reduction in Area, percent	Tensile Modulus, 10^3 ksi
		Room Temperature			
1L-1	103.5	90.7	5.0	4.4	14.7
1L-2	105.6	91.0	6.0	5.7	16.1
1L-3	109.2	95.6	4.0	4.7	15.2
Average	106.1	92.4	5.0	4.9	15.3
		400 F			
1L-4	78.2	67.0	4.5	7.9	13.8
1L-5	80.1	70.2	4.5	8.2	14.2
1L-6	77.6	64.8	4.5	7.6	12.6
Average	78.6	67.3	4.5	7.9	13.5
		800 F			
1L-7	60.6	45.4	7.0	8.0	11.4
1L-8	60.6	47.2	8.0	8.0	10.8
1L-9	64.8	44.6	9.0	9.4	13.9
Average	62.0	45.7	8.0	8.5	12.0

TABLE XXV. RESULTS OF COMPRESSION TESTS FOR Ti-6Al-4V POWDER METALLURGY PRODUCT

Specimen Number		0.2 Percent Offset Yield Strength, ksi	Compressive Modulus, 10^3 ksi
		Room Temperature	
2L-1		97.3	14.4
2L-2		98.4	14.2
2L-3		97.3	15.0
	Average	97.7	14.5
		400 F	
2L-4		70.5	12.6
2L-5		70.9	12.7
2L-6		70.7	12.6
	Average	70.7	12.6
		800 F	
2L-7		50.1	11.7
2L-8		50.0	10.9
2L-9		50.0	11.4
	Average	50.0	11.3

TABLE XXVI. RESULTS OF PIN SHEAR TESTS FOR Ti-6Al-4V POWDER METALLURGY PRODUCT

Specimen Number		Shear Ultimate Strength, ksi
	Room Temperature	
4L-1		71.7
4L-2		73.8
4L-3		72.4
	Average	72.6
	400 F	
4L-4		59.3
4L-5		60.2
4L-6		60.0
	Average	59.8
	800 F	
4L-7		45.5
4L-8		45.9
4L-9		45.7
	Average	45.7

TABLE XXVII. RESULTS OF BEARING TESTS AT e/D = 1.5 AND e/D = 2.0 FOR Ti-6Al-4V POWDER METALLURGY PRODUCT

Specimen Number	Bearing Ultimate Strength, ksi		Bearing Yield Strength, ksi	
	e/D = 1.5	e/D = 2.0	e/D = 1.5	e/D = 2.0
		Room Temperature		
T-1	172.2	215.8	151.2	169.9
T-2	180.2	229.8	154.5	178.3
T-3	178.0	230.9	148.2	170.8
Average	176.8	225.5	151.3	173.0
		400 F		
T-5	141.7	169.0	121.2	136.7
T-7	136.9	169.2	114.4	131.5
Average	139.3	169.1	117.8	134.1
		800 F		
T-6	116.3	142.7	98.1	109.6
T-8	112.3	140.9	90.3	102.2
Average	114.3	141.8	94.2	105.9

TABLE XXVIII. RESULTS OF CHARPY IMPACT TESTS AT ROOM TEMPERATURE FOR Ti-6Al-4V POWDER METALLURGY PRODUCT

Specimen Number	Energy, ft/lbs
10L-1	13.5
10L-2	14.0
10L-3	17.0
10L-4	11.5
10L-5	10.0

TABLE XXIX. RESULTS OF AXIAL LOAD FATIGUE TESTS FOR UNNOTCHED Ti-6Al-4V PM PRODUCT AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	Cycles to Failure
	Room Temperature	
5-1	100	2,200
5-2	80	12,600
5-3	60	58,800
5-4	50	75,900
5-5	35	220,300
5-7	33.5	673,500
5-6	30	502,900
5-20	25	902,800
5-11	20	10,000,000(a)
	400 F	
5-8	80	1,000
5-9	60	7,300
5-12	50	37,400
5-10	40	112,300
5-13	35	227,600
5-11	30	10,000,000(a)
	800 F	
5-14	60	6,100
5-17	50	6,500
5-19	45	33,200
5-15	40	76,400
5-18	35	510,300
5-16	30	2,975,800
5-21	25	964,000

(a) Did Not Fail

TABLE XXX. RESULTS OF AXIAL LOAD FATIGUE TESTS FOR NOTCHED (K_t = 3.0) Ti-6Al-4V PM PRODUCT AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	Cycles to Failure
	Room Temperature	
5-54	40	23,500
5-51	35	87,800
5-31	30	49,400
5-33	25	86,100
5-34	20	112,200
5-35	15	339,900
5-53	12.5	10,000,000(a)
5-36	10	10,000,000(a)
	400 F	
5-49	45	2,300
5-48	40	10,400
5-47	35	51,900
5-46	30	203,600
5-45	25	1,224,600
5-50	22.5	9,809,500
	800 F	
5-52	35	6,900
5-41	30	27,800
5-37	25	24,200
5-38	25	25,300
5-42	25	169,500
5-43	22.5	1,387,900
5-44	20	10,000,000(a)
5-40	15	10,000,000(a)

(a) Did Not Fail

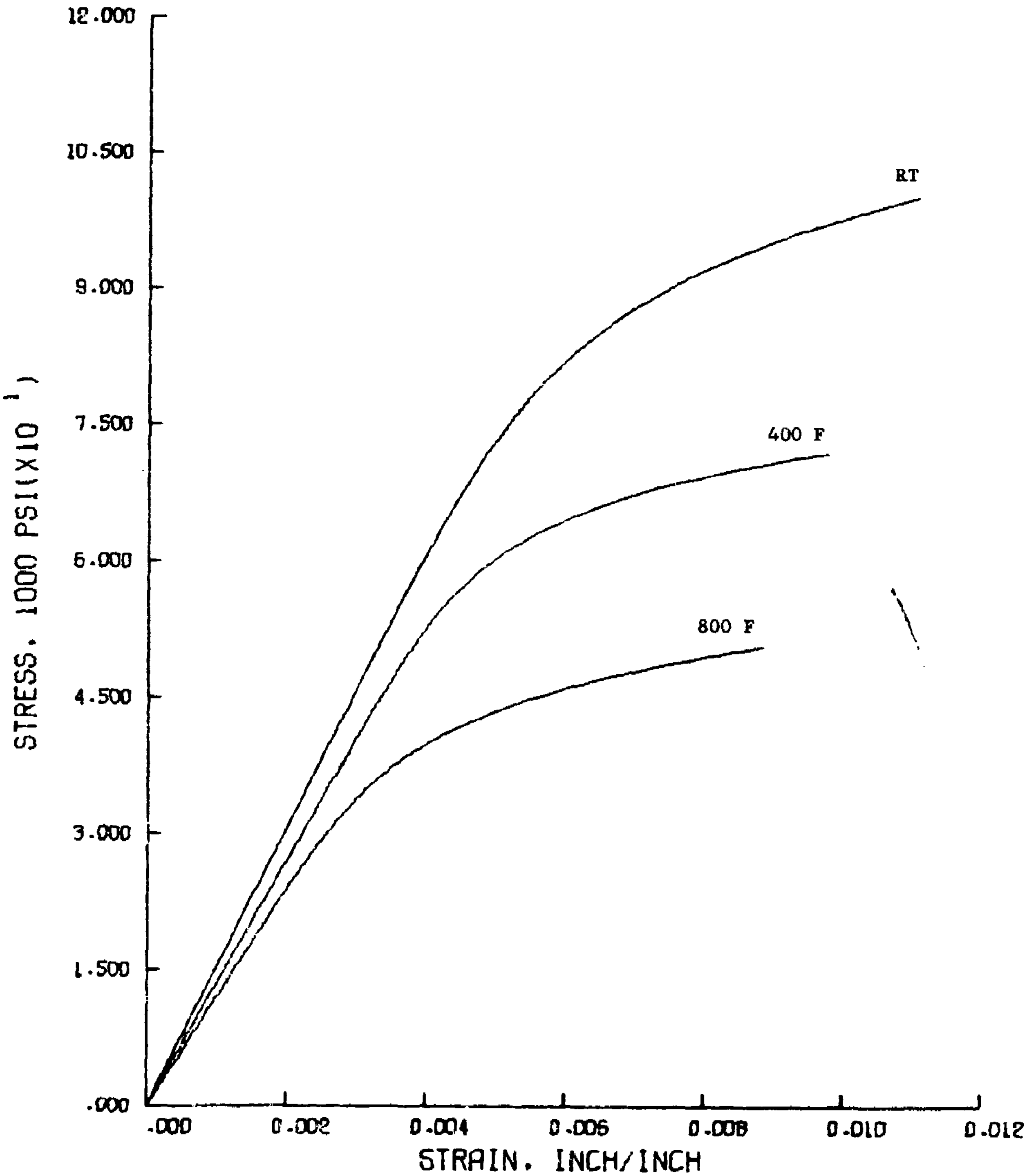

FIGURE 34. TYPICAL TENSILE STRESS-STRAIN CURVES AT TEMPERATURE FOR Ti-6Al-4V POWDER METALLURGY PRODUCT

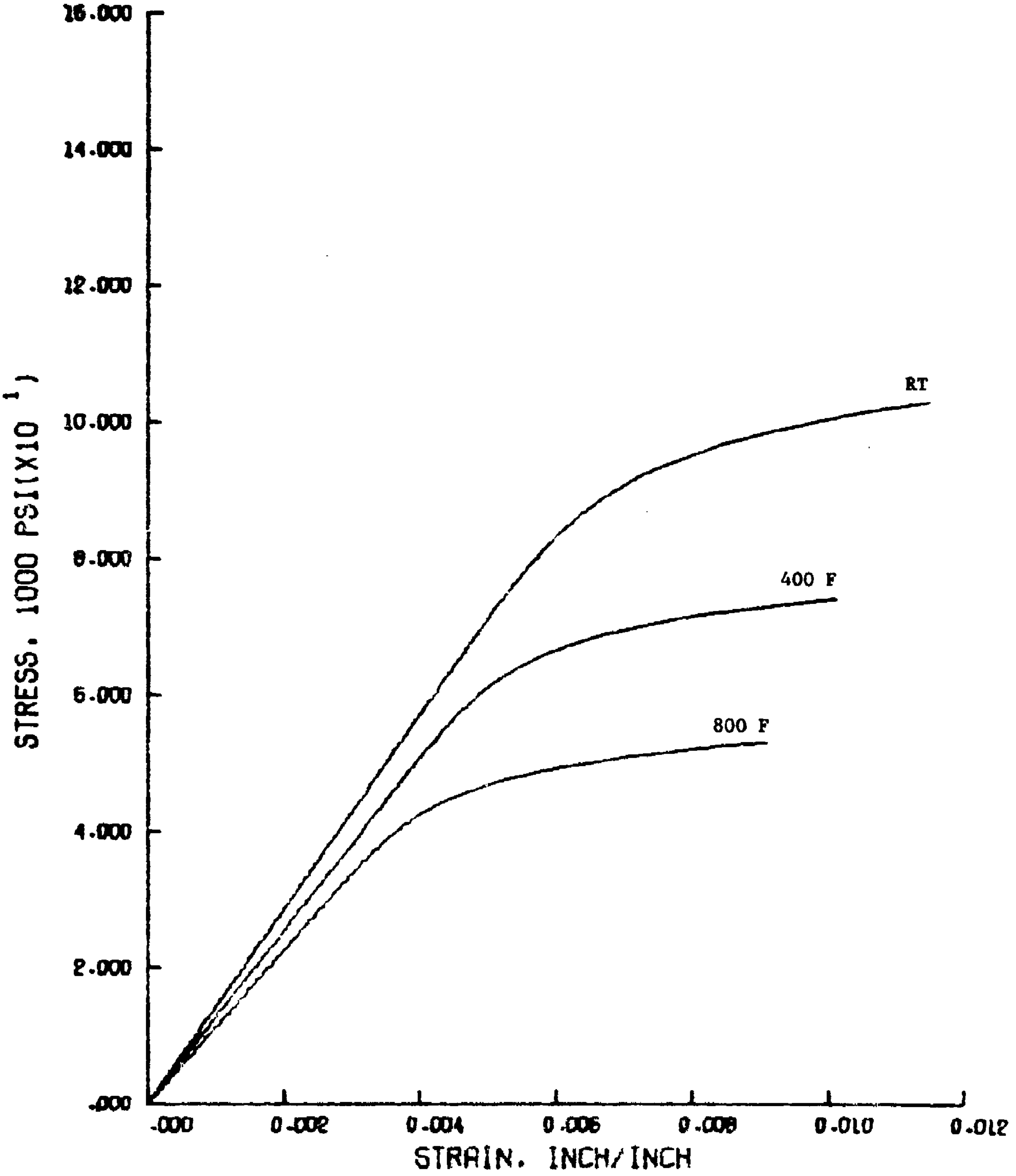

FIGURE 35. TYPICAL COMPRESSIVE STRESS-STRAIN CURVES AT TEMPERATURE FOR Ti-6Al-4V POWDER METALLURGY PRODUCT

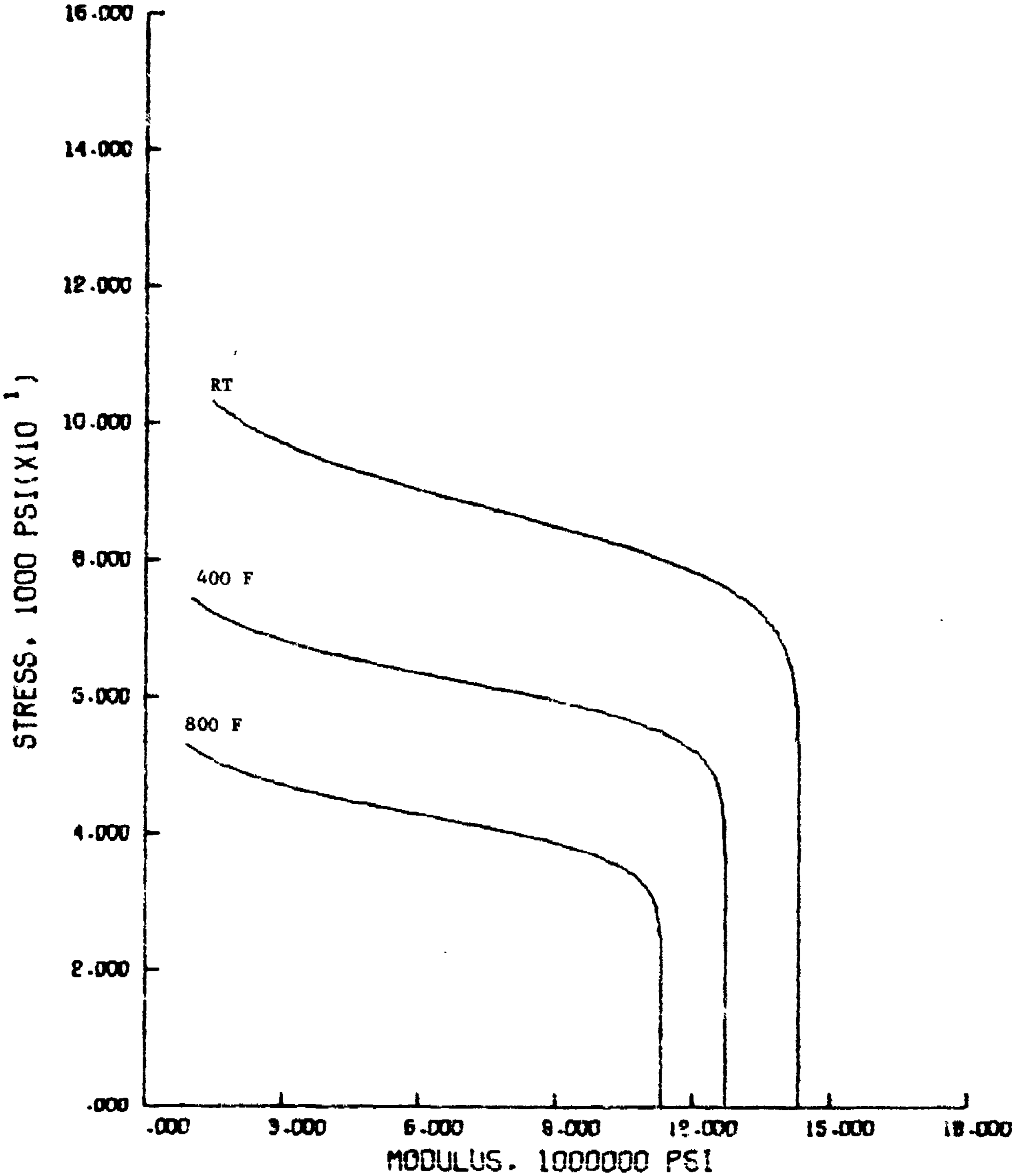

FIGURE 36. TYPICAL COMPRESSIVE TANGENT-MODULUS CURVES AT TEMPERATURE FOR Ti-6Al-4V POWDER METALLURGY PRODUCT

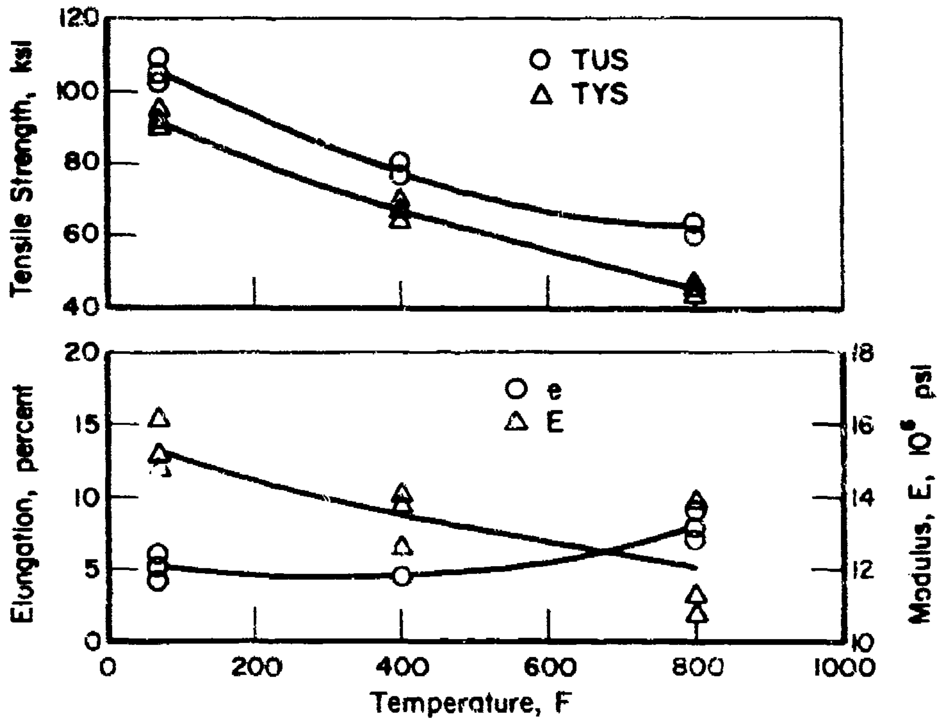

FIGURE 37. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF Ti-6Al-4V PM PRODUCT

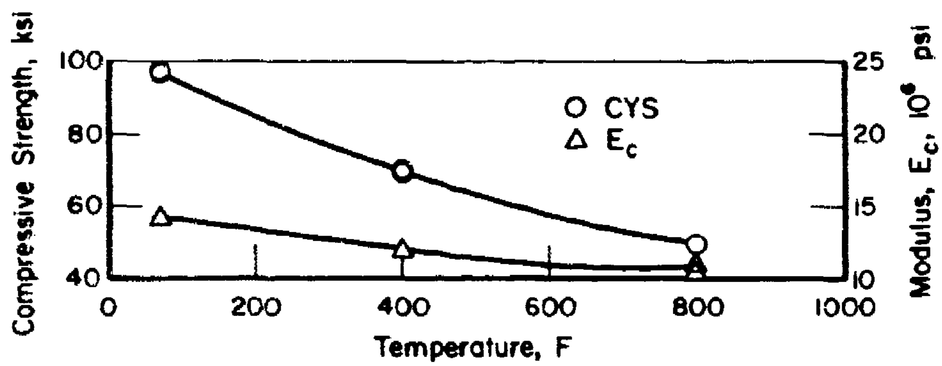

FIGURE 38. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF Ti-6Al-4V PM PRODUCT

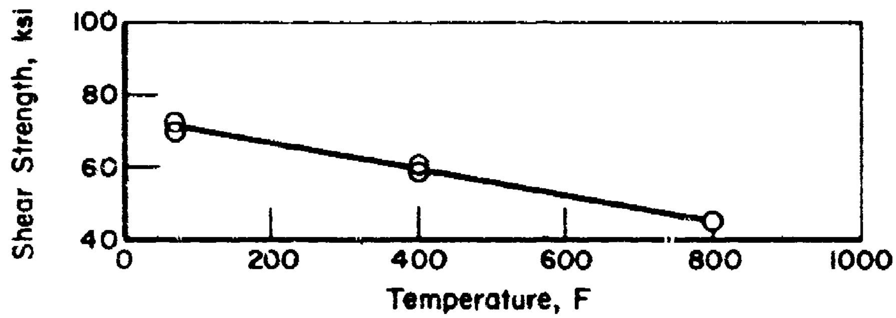

FIGURE 39. EFFECT OF TEMPERATURE ON THE SHEAR PROPERTIES OF Ti-6Al-4V PM PRODUCT

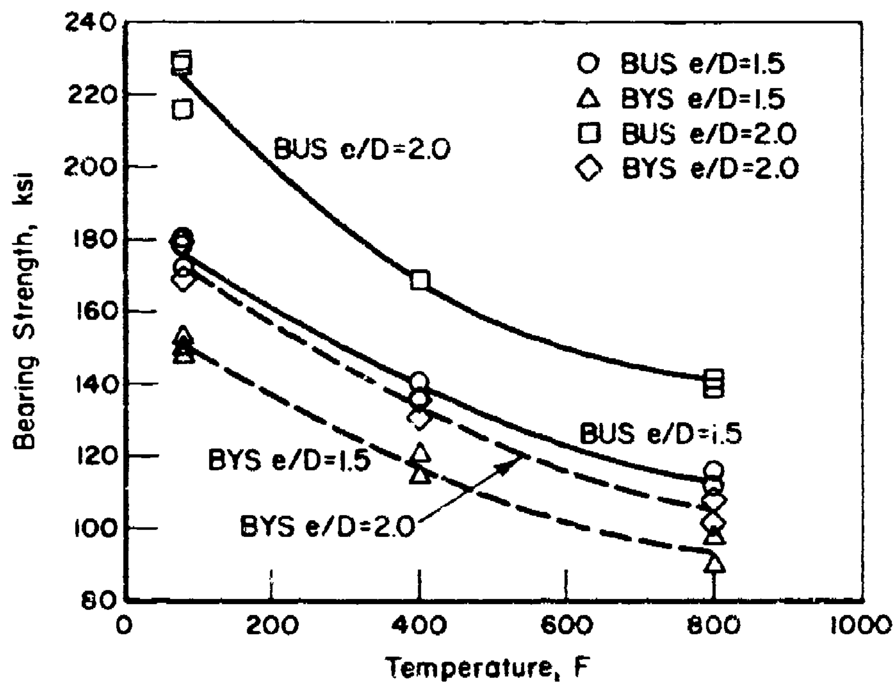

FIGURE 40. EFFECT OF TEMPERATURE ON THE BEARING PROPERTIES OF Ti-6Al-4V PM PRODUCT

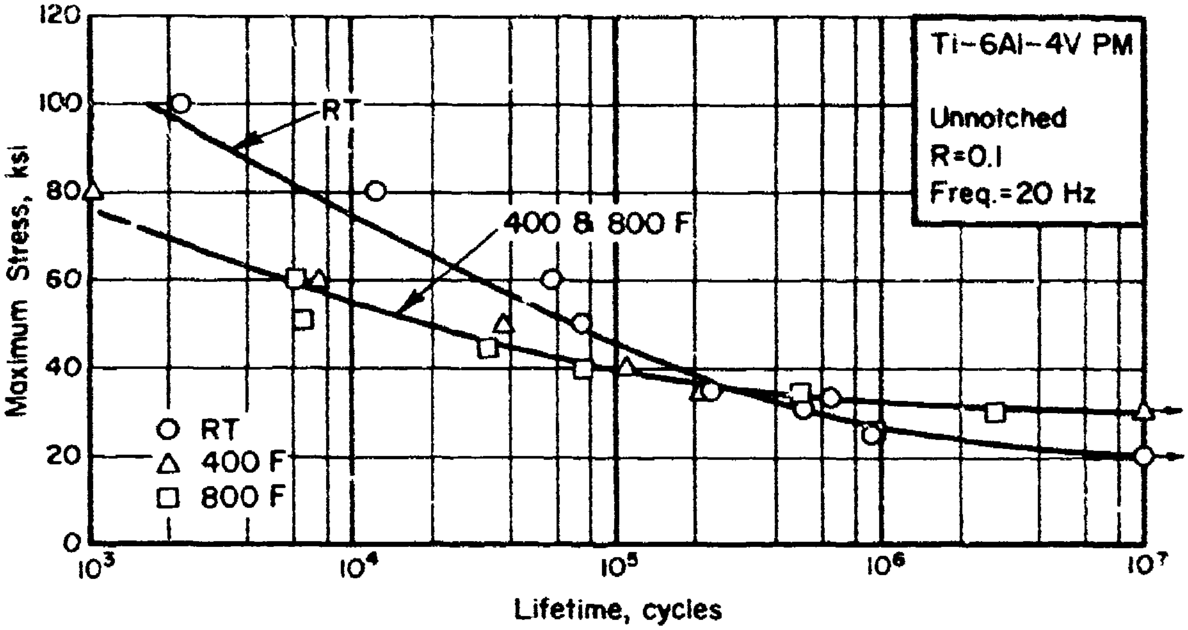

FIGURE 41. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED Ti-6Al-4V PM PRODUCT

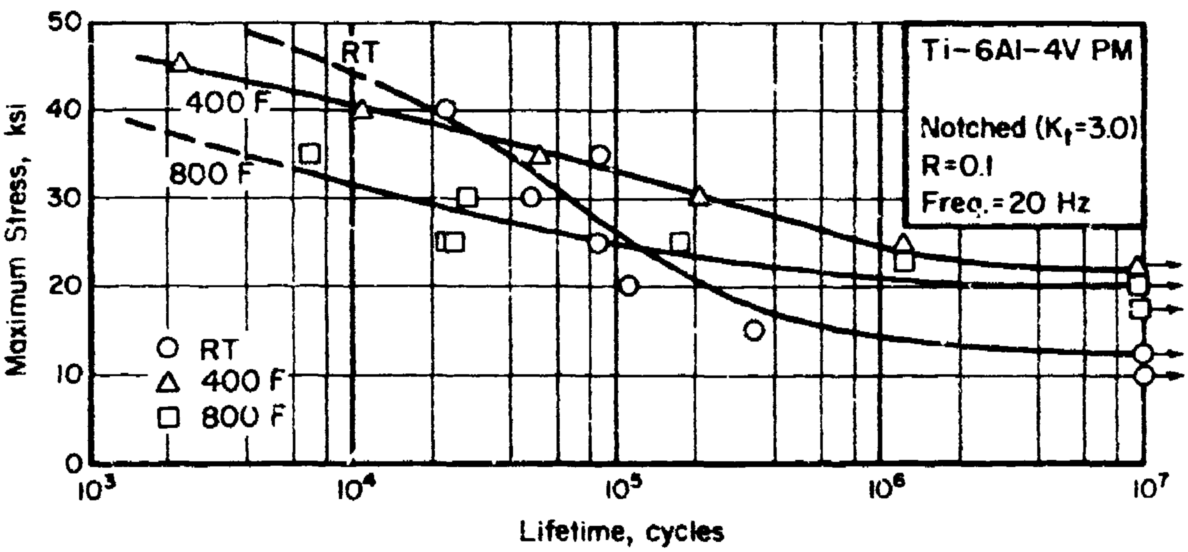

FIGURE 42. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) Ti-6Al-4V PM PRODUCT

7050-T73 Aluminum Alloy Extrusions

Material Description

Alloy 7050 is an Al-Zn-Mg-Cu alloy developed by the Alcoa Research Laboratories supported by the Naval Air Systems Command and the Air Force Materials Laboratory. When heat treated and aged to the -T73 temper, thick 7050 plate and hand forgings exhibit strengths equal to or exceeding those of 7079-T6XX products combined with improved fracture toughness and a high resistance to exfoliation and stress-corrosion cracking. The alloy differs from conventional 7XXX series aluminum alloys in that zirconium is added and chromium and manganese are restricted in order to minimize quench sensitivity.

The material used in this evaluation was an extrusion supplied by Alcoa about 3/4-inch thick by 24-inches wide by 24-inches long. It is identified as Section 303002. Alloy 7050 is produced within the following composition limits:

Chemical Composition	Percent
Copper	2.0 to 2.8
Iron	0.15 max
Silicon	0.12 max
Manganese	0.10 max
Magnesium	1.9 to 2.6
Zinc	5.7 to 6.7
Chromium	0.04 max
Titanium	0.06 max
Aluminum	Balance

Processing and Heat Treating

The specimen layout is shown in Figure 43. Specimens were tested in the as-received -T73 temper.

Test Results

Tension. Results of tests in the longitudinal and transverse directions at room temperature, 250 F, and 350 F are shown in Table XXXI. Typical stress-strain curves at temperature are presented in Figures 44 and 45. Effect-of-temperature curves are shown in Figure 50.

Compression. Results of tests in the longitudinal and transverse directions at room temperature, 250 F, and 350 F are given in Table XXXII.

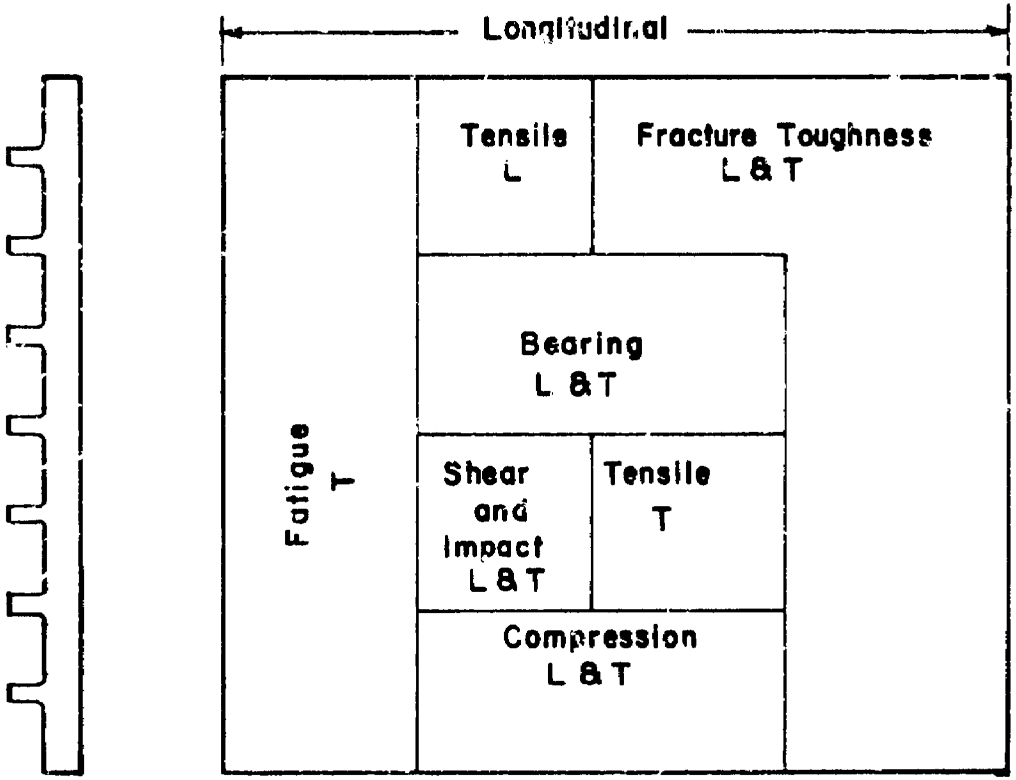

FIGURE 43. SPECIMEN AREA LAYOUT FOR 7050-T73 ALUMINUM ALLOY EXTRUSIONS

Typical stress-strain and tangent-modulus curves at temperature are presented in Figures 46 through 49. Effect-of-temperature curves are presented in Figure 51.

Shear. Results of pin shear tests for the longitudinal and transverse directions at room temperature, 250 F, and 350 F are given in Table XXXIII. Effect-of-temperature curves are presented in Figure 52.

Bearing. Results of bearing tests at e/D = 1.5 and e/D = 2.0 for longitudinal and transverse specimens at room temperature, 250 F, and 350 F are given in Table XXXIV. Effect-of-temperature curves are presented in Figure 53.

Impact. Results of Charpy tests for longitudinal and transverse specimens at room temperature are given in Table XXXV.

Fracture Toughness. Compact-tension-type tests were conducted at room temperature for longitudinal and transverse specimens. Results are presented in Table XXXVI. The candidate K_Q values are considered valid K_{Ic} values per ASTM E399. Some crack-propagation tests were also performed. Results are shown in Figure 54.

Fatigue. Axial load fatigue test results for transverse unnotched and notched specimens at room temperature, 250 F, and 350 F are shown in Tables XXXVII and XXXVIII. S-N curves are presented in Figures 55 and 56.

Stress Corrosion. Tests were conducted as explained in the experimental procedures section of this report. No cracks or failures occurred in the test duration.

Thermal Expansion. The coefficient of thermal expansion for this material is 12.8×10^{-6} in/in/F (68 - 212 F).

Density. The density of this material is 0.102 lb/in^3.

TABLE XXXI. RESULTS OF TENSILE TESTS ON 7050-T73 ALUMINUM ALLOY EXTRUSIONS

Specimen Number	Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 1 Inch, percent	Reduction in Area, percent	Tensile Modulus, 10^3 ksi
		Longitudinal at Room Temperature			
1L-1	77.1	67.3	16	45.7	9.7
1L-2	77.9	68.1	16	44.1	9.7
1L-3	77.1	67.1	16	46.3	9.7
Average	77.4	67.5	16	45.4	9.7
		Transverse at Room Temperature			
1T-1	74.6	65.4	12	32.0	9.7
1T-2	76.6	66.5	13	37.8	9.7
1T-3	76.2	66.4	13	34.0	9.7
Average	75.8	66.1	13	34.0	9.7
		Longitudinal at 250 F			
1L-4	62.5	61.7	20	49.3	10.6
1L-5	63.9	62.4	18	56.9	9.9
1L-6	61.8	60.2	19	54.2	10.1
Average	62.7	61.4	19	53.5	10.2
		Transverse at 250 F			
1T-4	61.1	59.0	16	47.0	10.0
1T-5	59.9	58.3	18	48.7	9.6
1T-6	60.4	58.5	16	48.9	9.6
Average	60.5	58.6	16.7	48.2	9.7
		Longitudinal at 350 F			
1L-7	50.7	49.8	16	54.3	9.4
1L-8	49.8	49.3	20	67.8	9.4
1L-9	50.5	49.6	21	68.1	8.2
Average	50.3	49.6	19	63.4	9.0
		Transverse at 350 F			
1T-7	49.0	48.4	16	56.9	9.4
1T-8	49.1	48.6	16	58.9	9.4
1T-9	48.9	48.7	14	54.2	9.5
Average	49.0	48.6	15.3	56.7	9.4

TABLE XXXII. RESULTS OF COMPRESSION TESTS ON 7050-T73 ALUMINUM ALLOY EXTRUSIONS

Specimen Number		0.2 Percent Offset Yield Strength, ksi	Compressive Modulus, 10^3 ksi
	Longitudinal at Room Temperature		
2L-1		68.1	10.0
2L-2		67.7	10.3
2L-3		67.5	10.4
	Average	67.8	10.3
	Transverse at Room Temperature		
2T-1		69.6	10.9
2T-2		69.6	11.3
2T-3		69.3	11.4
	Average	69.5	11.2
	Longitudinal at 250 F		
2L-4		62.2	10.9
2L-5		61.5	9.6
2L-6		61.6	9.7
	Average	61.7	10.1
	Transverse at 250 F		
2T-4		63.7	9.2
2T-5		63.2	9.6
2T-6		62.0	9.7
	Average	63.0	9.5
	Longitudinal at 350 F		
2L-7		51.8	8.6
2L-8		51.5	8.6
2L-9		50.9	8.7
	Average	51.4	8.6
	Transverse at 350 F		
2T-7		51.9	9.4
2T-8		53.5	8.6
2T-9		53.0	8.7
	Average	52.8	8.9

TABLE XXXIII. **RESULTS OF PIN SHEAR TESTS FOR 7050-T73 ALUMINUM ALLOY EXTRUSIONS**

Specimen Number		Shear Ultimate Strength, ksi
Longitudinal at Room Temperature		
4L-1		45.8
4L-2		44.0
4L-3		48.6
	Average	46.1
Transverse at Room Temperature		
4T-1		44.8
4T-2		43.7
4T-3		44.9
	Average	44.5
Longitudinal at 250 F		
4L-4		36.0
4L-5		36.0
4L-6		37.6
	Average	36.5
Transverse at 250 F		
4T-4		36.7
4T-5		34.2
4T-6		34.0
	Average	35.0
Longitudinal at 350 F		
4L-7		29.2
4L-8		30.1
4L-9		30.0
	Average	29.8
Transverse at 350 F		
4T-7		29.9
4T-8		28.7
4T-9		28.2
	Average	28.9

TABLE XXXIV. RESULTS OF BEARING TESTS AT e/D = 1.5 AND e/D = 2.0 FOR 7050-T73 ALUMINUM ALLOY EXTRUSION

Specimen Number		Bearing Ultimate Strength, ksi		Bearing Yield Strength, ksi	
		e/D = 1.5	e/D = 2.0	e/D = 1.5	e/D = 2.0
Longitudinal at Room Temperature					
L-1		111.8	148.0	87.8	103.1
L-2		108.7	150.7	87.2	105.0
L-3		107.4	151.1	88.7	110.0
	Average	109.3	149.9	87.9	106.0
Transverse at Room Temperature					
T-1		104.0	152.0	86.1	111.7
T-2		107.9	148.2	89.7	110.6
T-3		108.1	139.0	88.7	104.3
	Average	106.7	146.4	88.2	108.9
Longitudinal at 250 F					
L-4		93.0	116.8	80.0	94.1
L-5		90.9	119.9	78.6	96.4
L-6		92.5	113.7	80.1	90.1
	Average	92.1	116.8	79.6	93.5
Transverse at 250 F					
T-4		93.0	111.0	79.6	91.9
T-5		86.6	118.8	74.1	96.4
T-6		91.7	119.2	79.2	98.4
	Average	90.4	116.3	77.6	95.6
Longitudinal at 350 F					
L-7		73.3	97.4	66.7	80.0
L-8		75.8	93.3	68.3	74.6
L-9		77.4	93.0	70.4	77.9
	Average	75.5	94.6	68.5	77.5
Transverse at 350 F					
T-7		75.3	94.1	68.5	75.0
T-8		75.6	93.8	68.8	75.9
T-9		76.5	90.6	70.1	76.0
	Average	75.8	92.8	69.1	75.6

TABLE XXXV. RESULTS OF CHARPY TESTS AT ROOM TEMPERATURE FOR 7050-T73 ALUMINUM ALLOY EXTRUSIONS

Specimen Number		Energy, ft/lbs
	Longitudinal	
10L-1		5.5
10L-2		6.0
10L-3		7.0
	Average	6.2
	Transverse	
10T-1		5.0
10T-2		7.5
10T-3		6.0
	Average	6.2

TABLE XXXVI. RESULTS OF COMPACT TENSION TYPE FRACTURE TOUGHNESS TESTS FOR 7050-T73 ALUMINUM ALLOY EXTRUSIONS

Specimen Number	W, inches	B, inches	a, inches	F_Q, pounds	P_{max}, pounds	f(a/w)	K_Q
			Longitudinal (L-T)				
6L-1	1.5	.75	0.824	2500	2600	11.24	30.6
6L-2	1.5	.75	0.750	3400	3550	9.60	35.5
6L-3	1.5	.75	0.751	3000	3000	9.61	31.4
						Average	32.5
			Transverse (T-L)				
6T-1	1.5	.75	0.748	3300	3400	9.55	34.3
6T-2	1.5	.75	0.756	2950	2950	9.74	31.3
6T-3	1.5	.75	0.750	3250	3300	9.60	33.9
						Average	33.2

TABLE XXXVII. RESULTS OF AXIAL LOAD FATIGUE TESTS FOR UNNOTCHED TRANSVERSE 7050-T73 ALUMINUM ALLOY EXTRUSION AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	Cycles to Failure
	Room Temperature	
5-3	80	5,200
5-5	75	8,200
5-2	70	13,000
5-6	65	24,000
5-4	60	70,300
5-7	55	132,300
5-1	50	5,792,000
5-26	50	3,806,500
5-27	45	6,052,900
	250 F	
5-14	70	1
5-9	65	16,900
5-11	60	26,000
5-13	55	199,000
5-12	50	243,200
5-23	45	1,506,500
5-24	40	4,878,100
5-29	35	10,000,000[(a)]
	350 F	
5-18	60	100
5-19	55	16,200
5-17	50	77,800
5-20	45	87,400
5-21	40	886,200
5-22	35	718,000
5-25	30	6,328,700

(a) Did not fail.

TABLE XXXVIII. RESULTS OF AXIAL LOAD FATIGUE TESTS FOR NOTCHED (K_t = 3.0) TRANSVERSE 7050-T73 ALUMINUM ALLOY EXTRUSION AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	Cycles to Failure
	Room Temperature	
5-31	45	3,100
5-32	35	10,300
5-36	30	18,500
5-33	25	22,200
5-34	20	56,500
5-35	15	226,000
5-37	10	971,700
5-55	10	10,000,000[a]
5-38	5	10,000,000[a]
	250 F	
5-53	40	7,300
5-43	35	12,100
5-44	30	19,200
5-42	25	42,100
5-45	20	60,900
5-39	15	178,600
5-40	10	550,700
5-54	10	10,000,000[a]
5-41	5	10,000,000[a]
	350 F	
5-51	35	6,800
5-48	30	11,200
5-50	25	31,200
5-47	20	62,700
5-49	15	102,800
5-52	15	127,900
5-46	10	10,000,000[a]

(a) Did not fail.

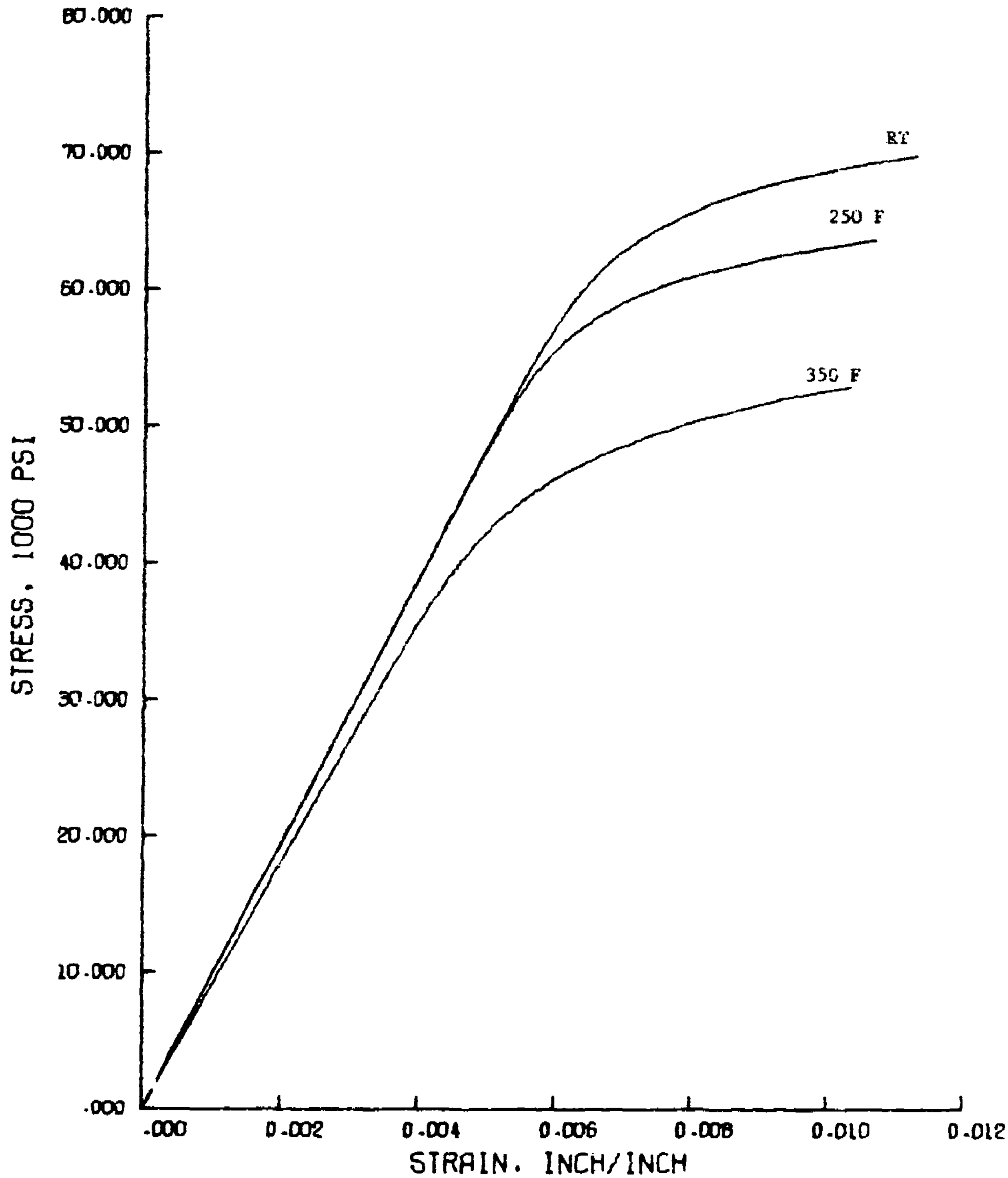

FIGURE 44. TYPICAL TENSILE LONGITUDINAL STRESS-STRAIN CURVES AT TEMPERATURE FOR 7050-T73 ALUMINUM ALLOY EXTRUSIONS

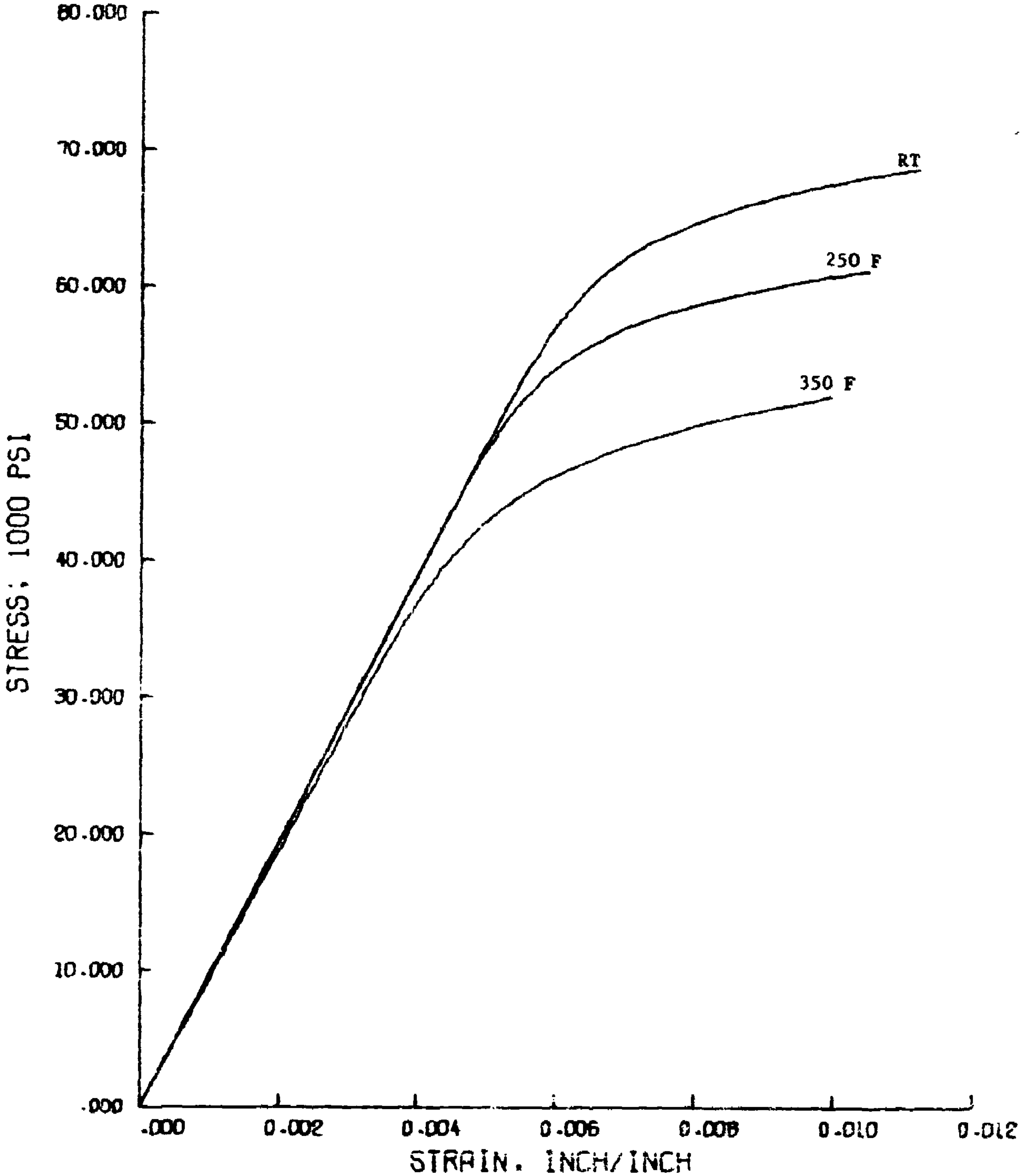

FIGURE 45. TYPICAL TENSILE TRANSVERSE STRESS-STRAIN CURVES AT TEMPERATURE FOR 7050-T73 ALUMINUM ALLOY EXTRUSIONS

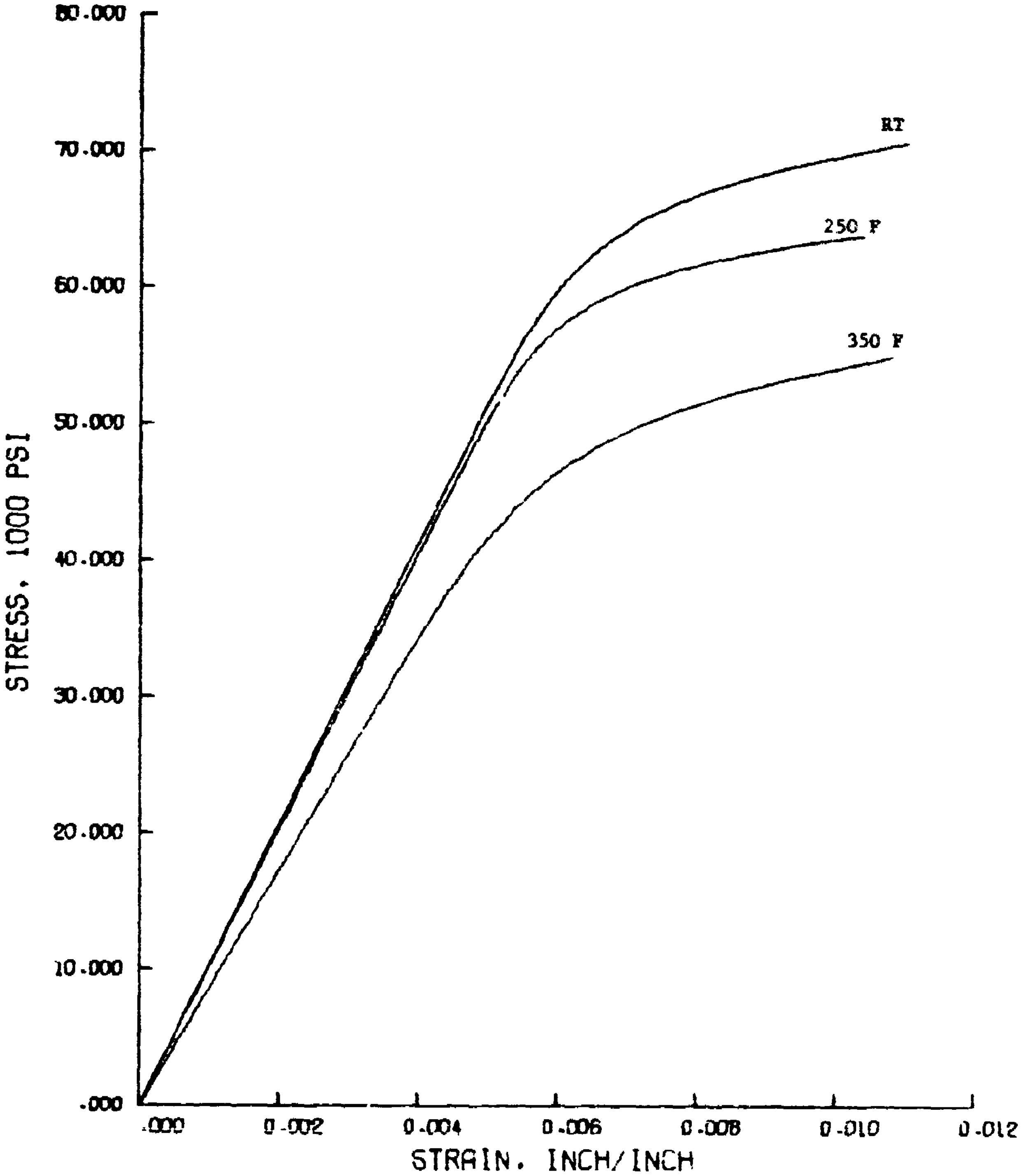

FIGURE 46. TYPICAL COMPRESSIVE LONGITUDINAL STRESS-STRAIN CURVES AT TEMPERATURE FOR 7050-T73 ALUMINUM ALLOY EXTRUSIONS

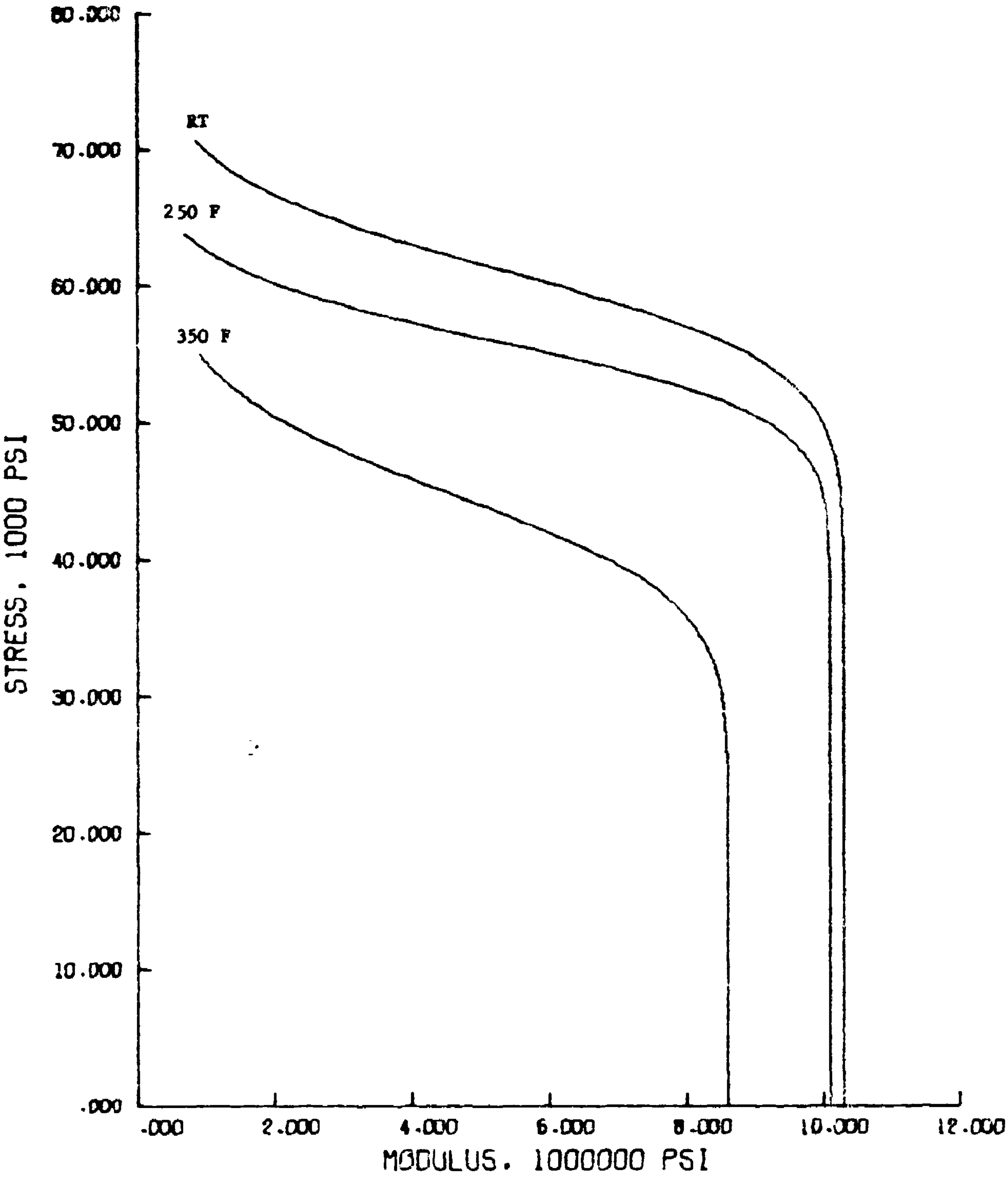

FIGURE 47. TYPICAL COMPRESSIVE LONGITUDINAL TANGENT-MODULUS CURVES AT TEMPERATURE FOR 7050-T73 ALUMINUM ALLOY EXTRUSIONS

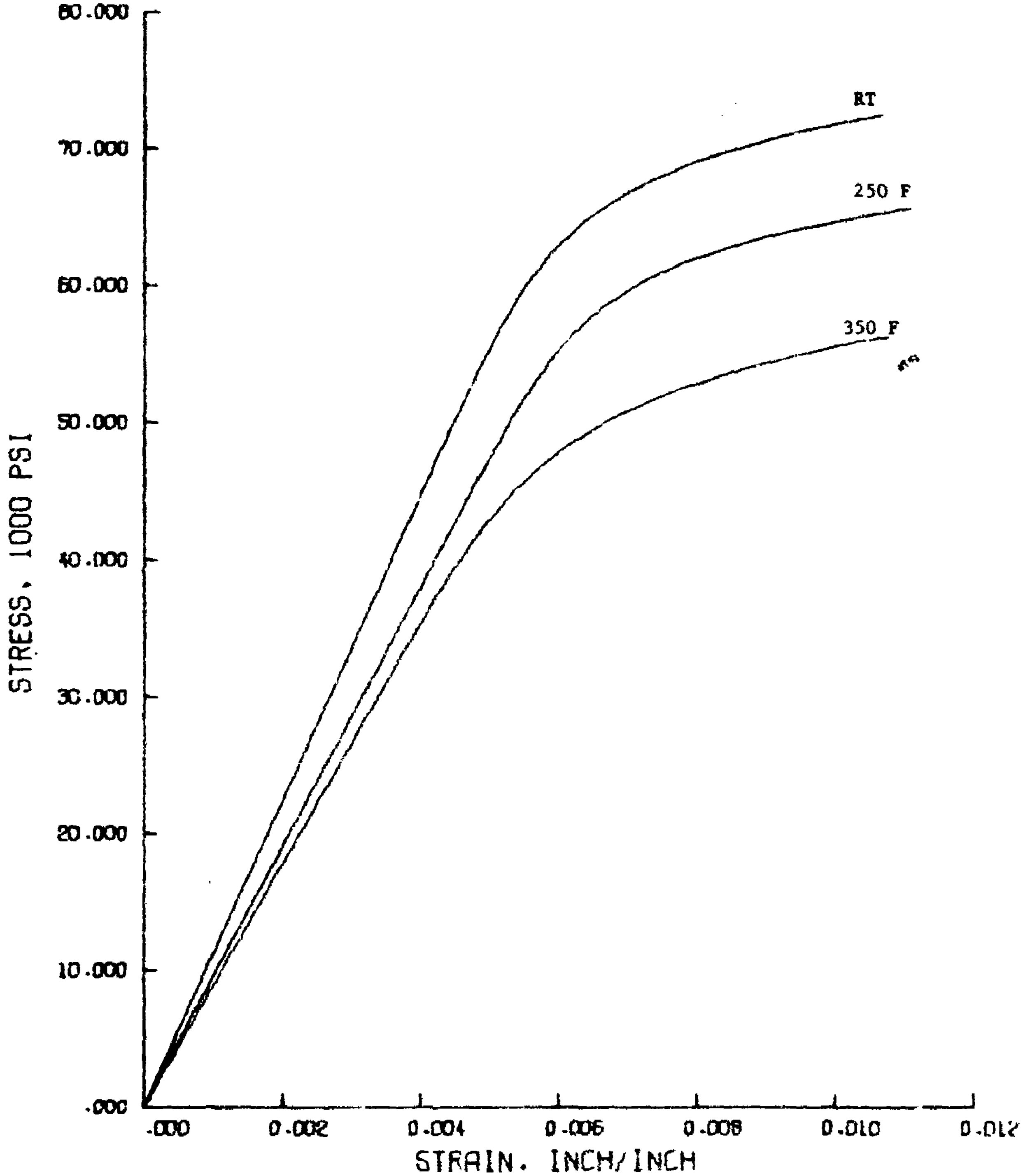

FIGURE 48. TYPICAL COMPRESSIVE TRANSVERSE STRESS-STRAIN CURVES AT TEMPERATURE FOR 7050-T73 ALUMINUM ALLOY EXTRUSIONS

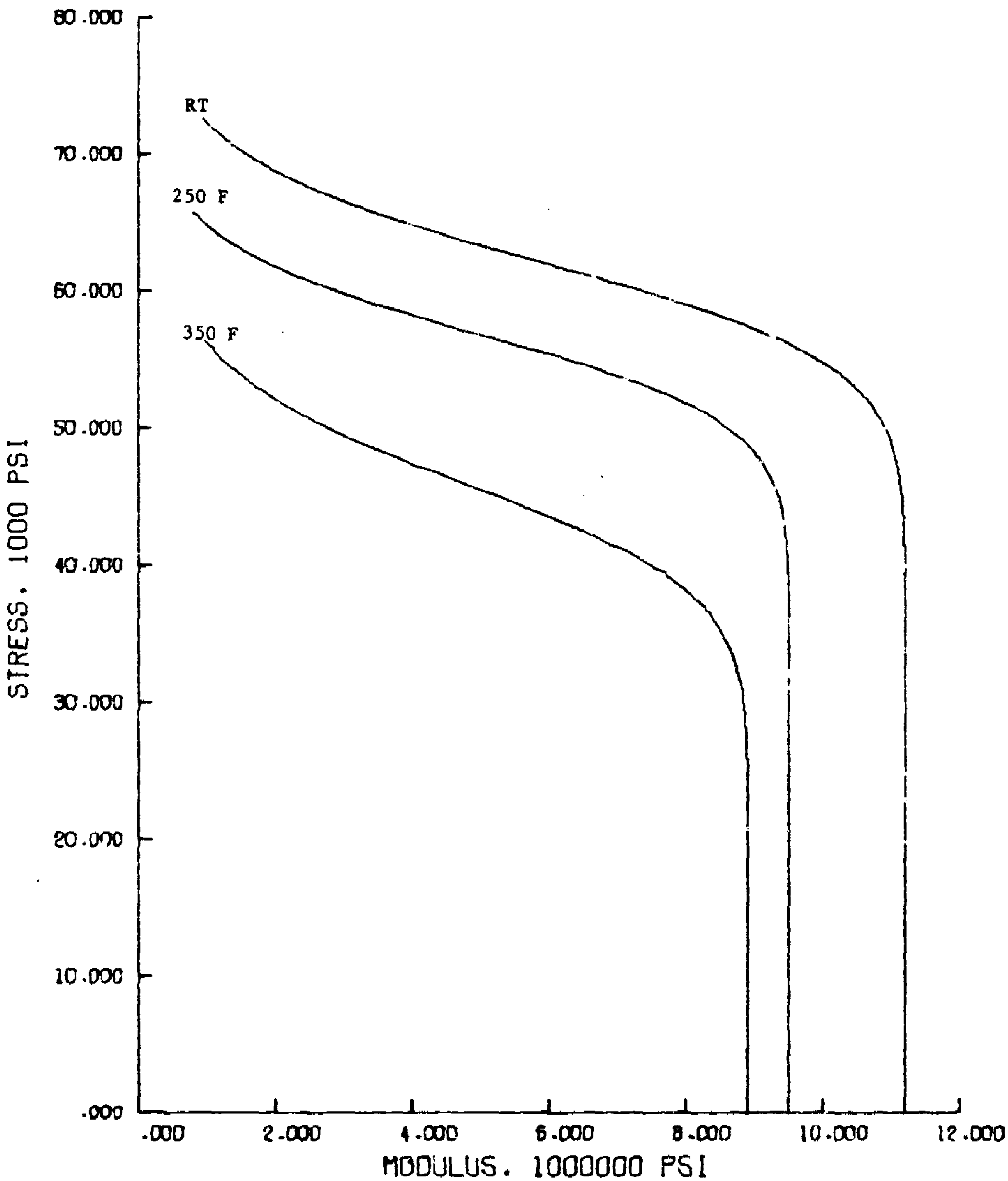

FIGURE 49. TYPICAL COMPRESSIVE TRANSVERSE TANGENT-MODULUS CURVES AT TEMPERATURE FOR 7050-T73 ALUMINUM ALLOY EXTRUSIONS

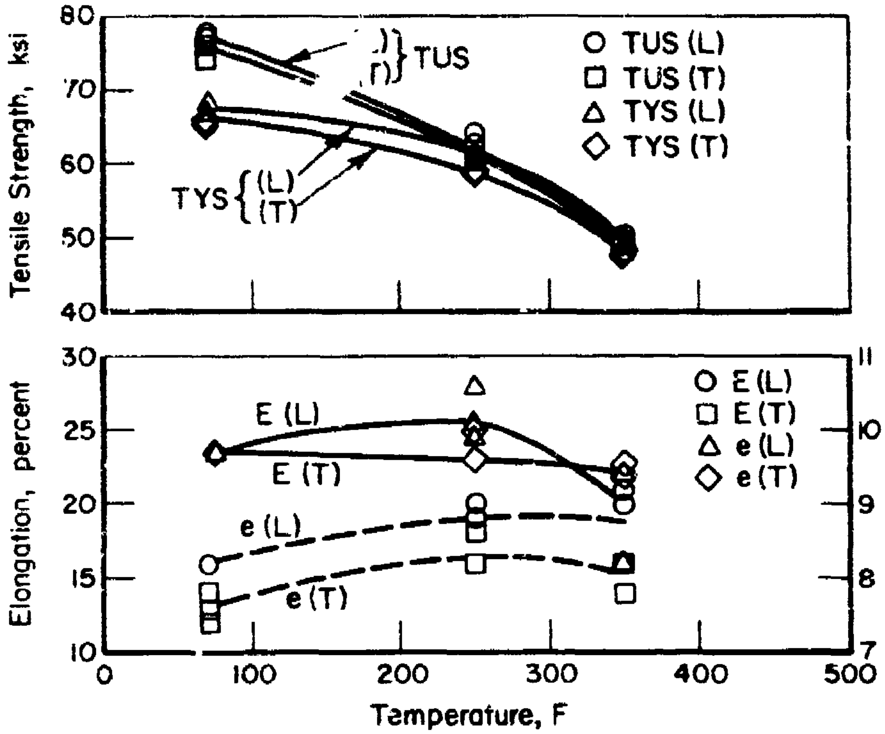

FIGURE 50. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 7050-T73 ALUMINUM ALLOY EXTRUSIONS

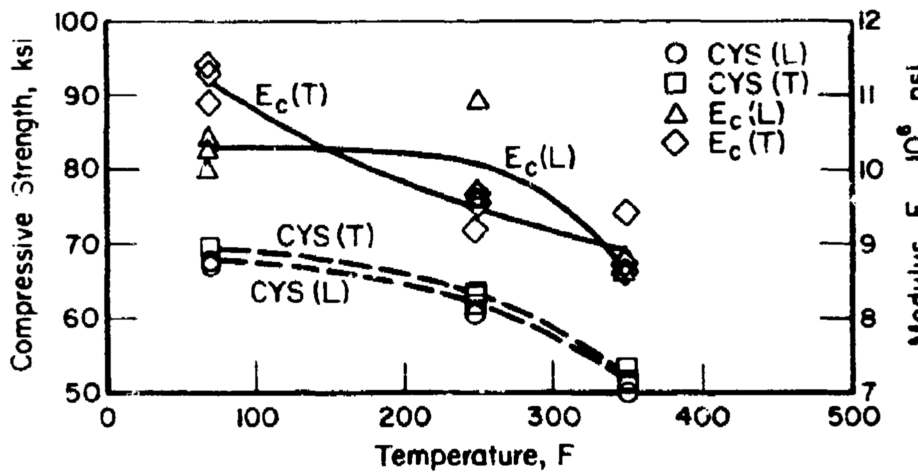

FIGURE 51. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 7050-T73 ALUMINUM ALLOY EXTRUSIONS

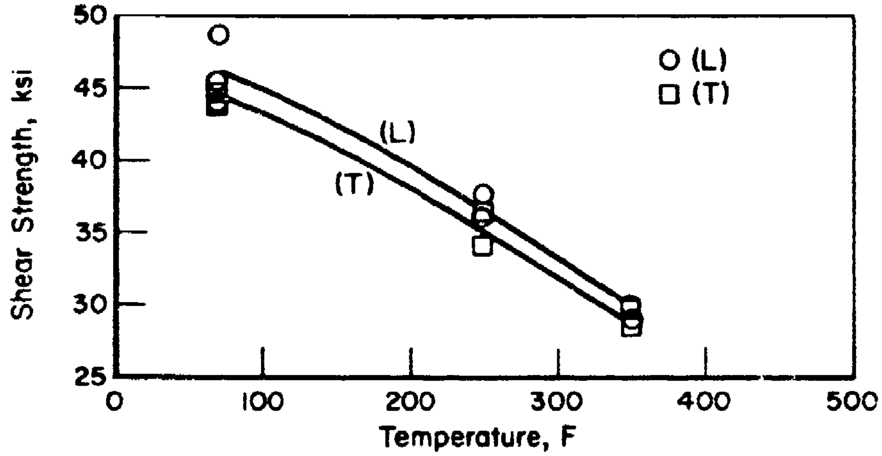

FIGURE 52. EFFECT OF TEMPERATURE ON THE SHEAR PROPERTIES OF 7050-T73 ALUMINUM ALLOY EXTRUSIONS

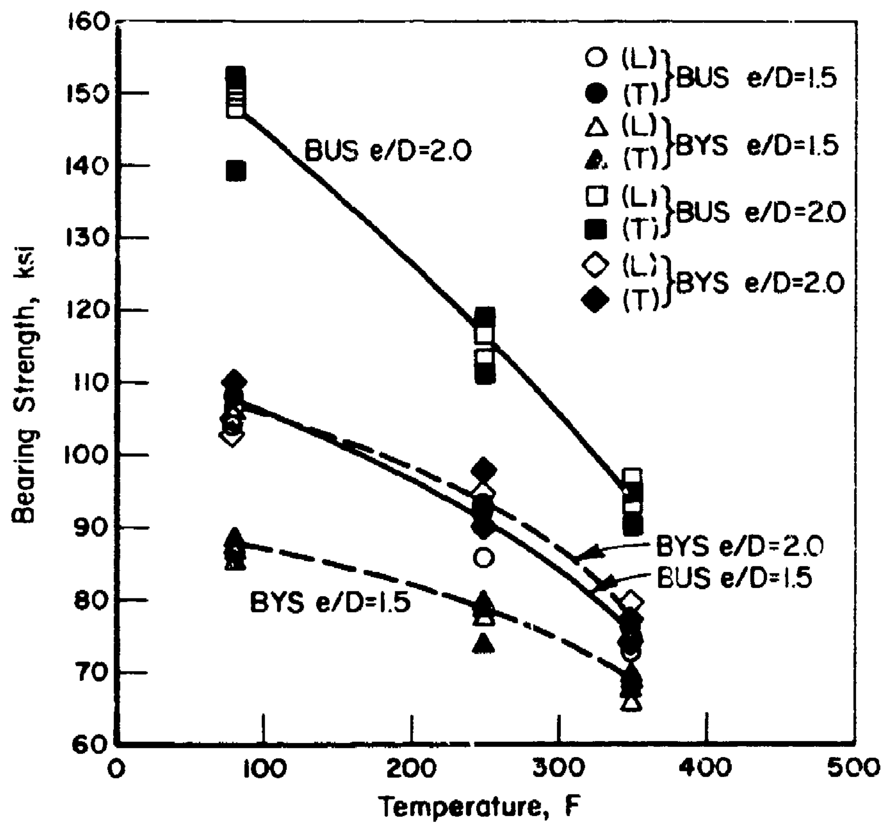

FIGURE 53. EFFECT OF TEMPERATURE ON THE BEARING PROPERTIES OF 7050-T73 ALUMINUM ALLOY EXTRUSIONS

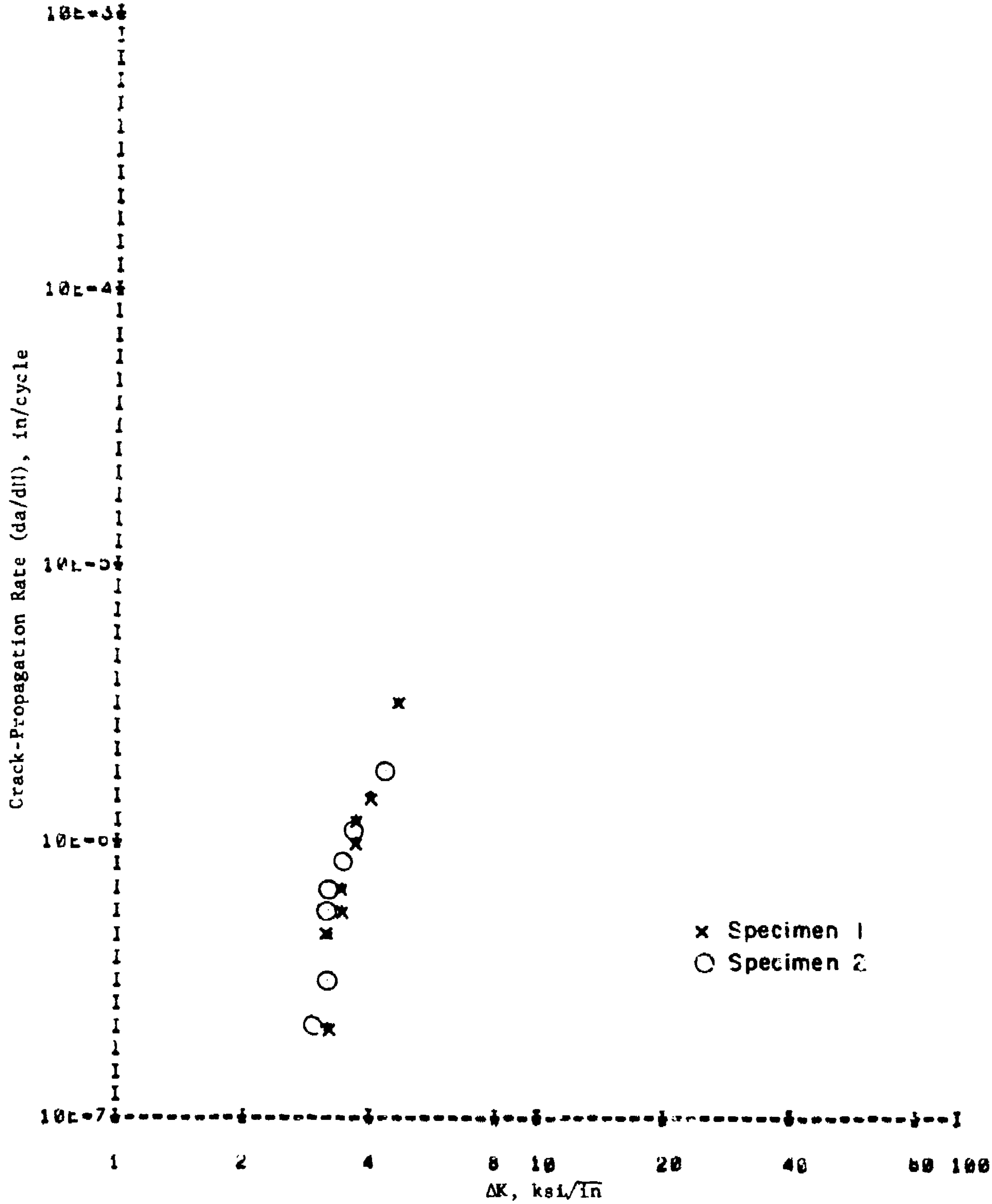

FIGURE 54. da/dN VERSUS ΔK FOR 7050-T73 ALUMINUM ALLOY EXTRUSIONS

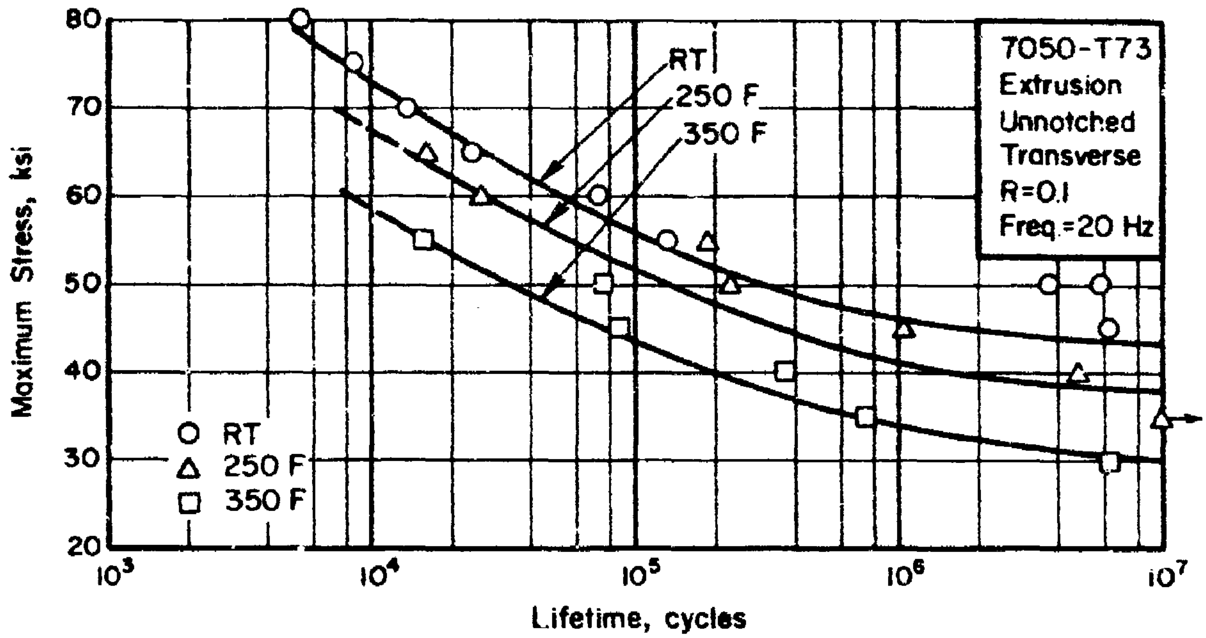

FIGURE 55. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED 7050-T73 ALUMINUM ALLOY EXTRUSIONS

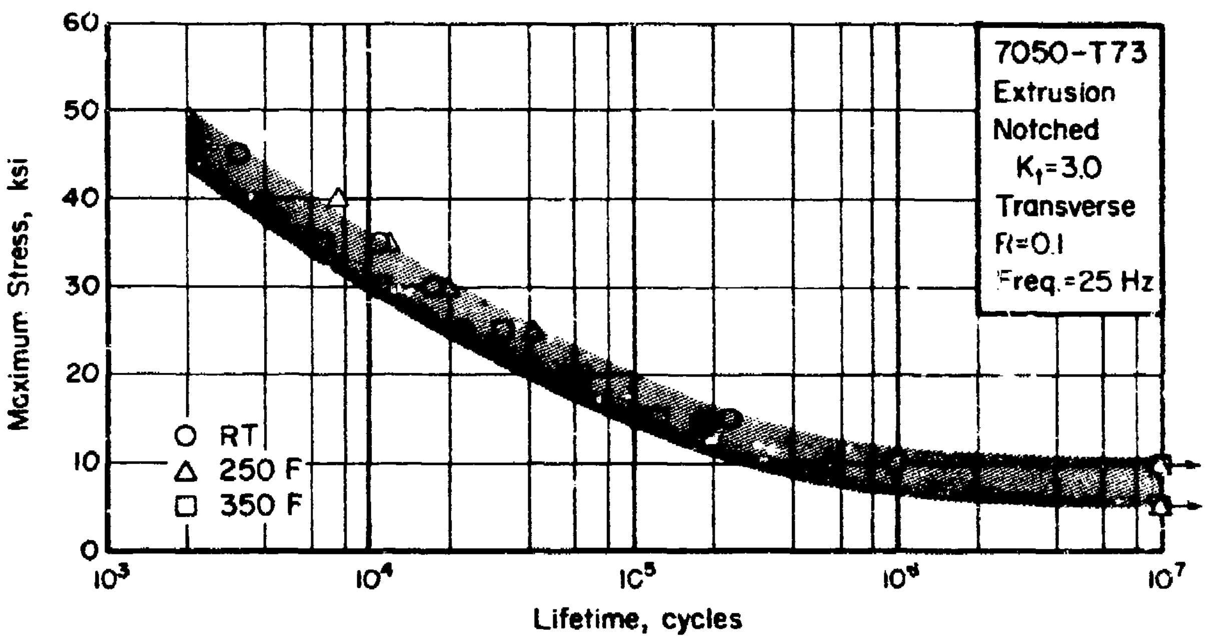

FIGURE 56. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) 7050-T73 ALUMINUM ALLOY EXTRUSIONS

Ti-10V-2Fe-3Al Alloy STOA Bar

Material Description

This alloy is a recent development of TIMET, a division of Titanium Metals Corporation of America. The alloy, metallurgically near-beta, is a high fracture toughness composition and is capable of attaining a variety of strength levels, depending on the selection of heat treatment. In the solution-treated and aged condition, the alloy shows creep-stability characteristics similar to the alpha-beta alloys at 600 F. A major advantage, other than toughness, is its excellent forgeability. It moves readily at temperatures below those required for Ti-6Al-4V.

TIMET believes the alloy should be considered for applications up to 600 F where medium to high strength and high toughness are required in sections up to five inches thick.

The nominal composition of Ti-10V-2Fe-3Al is:

Chemical Composition	Percent
Al	2.6 - 3.4
V	9.0 - 11.0
Fe	1.8 - 2.2
O	0.16 max
C	0.05 max
N	0.05 max
H	0.015 max
Others, Each	0.10 max
Others, Total	0.30 max

The material used for this evaluation was 3-inch round bar from TIMET heat F-1452.

Processing and Heat Treating

The material was heat treated as follows: 1 hour at 1400 F, furnace cooled plus 8 hours at 1050 F, air cooled. This is an intermediate strength, STOA condition. All specimens were sectioned in the longitudinal direction from the bar.

Test Results

Tension. Results of tensile tests for longitudinal specimens at room temperature, 400 F, and 800 F are given in Table XXXIX. Typical

stress-strain curves at temperature are shown in Figure 57. Effect-of-temperature curves are presented in Figure 60.

Compression. Results of compression tests at room temperature, 400 F, and 800 F are shown in Table XL. Typical stress-strain and tangent-modulus curves are shown in Figures 58 and 59. Effect-of-temperature curves are presented in Figure 61.

Shear. Results of pin shear tests at room temperature, 400 F, and 800 F are given in Table XLI. Effect-of-temperature curves are presented in Figure 62.

Bearing. Results of tests at e/D = 1.5 and e/D = 2.0 at room temperature, 400 F, and 800 F are shown in Table XLII. Effect-of-temperature curves are presented in Figure 63.

Impact. Results of longitudinal and transverse Charpy impact tests at room temperature are given in Table XLIII.

Fracture Toughness. Results of compact tension type tests are given in Table XLIV for longitudinal specimens at room temperature. Candidate K_Q values are valid K_{Ic} values per ASTM E399.

Fatigue. Fatigue test results for longitudinal unnotched and notched specimens at room temperature, 400 F, and 800 F are given in Tables XLV and XLVI S-N curves are presented in Figures 64 and 65.

Creep and Stress Rupture. Longitudinal specimens were tested at 700 F and 900 F. Tabular test results are given in Table LXI. Log-stress versus log-time curves are presented in Figure 66.

Stress Corrosion. Tests were conducted as described in the experimental procedures section of this report. No crack or failures occurred in the test duration.

Thermal Expansion. The coefficient of thermal expansion for this alloy is 5.4×10^{-6} in/in/F (RT to 800 F).

Density. The density of this material is 0.168 lb/in^3.

TABLE XXXIX. RESULTS OF LONGITUDINAL TENSILE TESTS ON STOA Ti-10V-2Fe-3Al ROUND BAR

Specimen Number	Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 1 Inch, percent	Reduction in Area, percent	Tensile Modulus, 10^3 ksi
		Room Temperature			
1L-1	141.7	137.7	18	60.5	14.7
1L-2	141.8	137.9	18	63.5	14.4
1L-3	141.0	137.8	19	63.5	15.0
Average	141.5	137.7	18.3	62.5	14.7
		400 F			
1L-4	121.1	107.4	23	67.3	14.5
1L-5	119.9	106.0	20	68.5	13.9
1L-6	118.5	105.7	21	65.9	13.7
Average	119.8	106.4	21.3	65.6	14.0
		800 F			
1L-7	96.5	78.6	21	79.6	11.5
1L-8	97.3	79.1	24	79.0	11.5
1L-9	97.8	79.0	22	79.9	11.3
Average	97.2	78.9	22.3	79.5	11.4

TABLE XL. RESULTS OF LONGITUDINAL COMPRESSION TESTS ON STOA Ti-10V-2Fe-3Al ROUND BAR

Specimen Number		0.2 Percent Offset Yield Strength, ksi	Compressive Modulus, 10^3 ksi
		Room Temperature	
2L-1		140.4	15.1
2L-2		139.2	15.4
2L-3		139.2	15.8
	Average	139.6	15.4
		400 F	
2L-4		107.7	14.8
2L-5		106.8	14.1
2L-6		107.6	13.9
	Average	107.4	14.3
		800 F	
2L-7		78.2	12.9
2L-8		78.2	12.6
2L-9		83.8	12.4
	Average	80.1	12.6

TABLE XLI. RESULTS OF LONGITUDINAL PIN SHEAR TESTS FOR STOA Ti-10V-2Fe-3Al ROUND BAR

Specimen Number		Shear Ultimate Strength, ksi
	Room Temperature	
4L-1		99.0
4L-2		95.5
4L-3		97.2
	Average	97.2
	400 F	
4L-4		81.6
4L-5		82.9
4L-6		82.3
	Average	82.3
	800 F	
4L-7		66.3
4L-8		68.1
4L-9		66.6
	Average	67.0

TABLE XLII. RESULTS OF BEARING TESTS AT e/D = 1.5 AND e/D = 2.0 FOR STOA Ti-10V-2Fe-3Al ROUND BAR

Specimen Number		Bearing Ultimate Strength, ksi		Bearing Yield Strength, ksi	
		e/D = 1.5	e/D = 2.0	e/D = 1.5	e/D = 2.0
			Room Temperature		
L-1		240.0	294.0	192.0	219.0
L-2		240.0	280.0	188.0	224.0
L-3		238.0	297.0	190.0	236.0
	Average	239.3	290.3	190.0	226.3
			400 F		
L-4		197.0	257.0	158.0	192.0
L-5		199.0	258.0	156.0	192.0
L-6		200.0	260.0	163.0	192.0
	Average	198.7	258.3	159.0	192.0
			800 F		
L-7		155.0	188.0	136.0	148.0
L-8		152.0	202.0	130.0	162.0
L-9		152.0	195.0	131.0	150.0
	Average	153.0	195.0	132.3	153.3

TABLE XLIII. RESULTS OF CHARPY IMPACT TESTS AT ROOM TEMPERATURE ON STOA Ti-10V-2Fe-3Al ROUND BAR

Specimen Number		Energy, ft/lbs.
	Longitudinal	
10L-1		26.5
10L-2		30.0
10L-3		30.0
	Average	28.8
	Transverse	
10T-1		20.5
10T-2		19.5
10T-3		17.0
	Average	19.0

TABLE XLIV. RESULTS OF COMPACT TENSION TESTS AT ROOM TEMPERATURE FOR STOA Ti-10V-2Fe-3Al ROUND BAR

Specimen Number	W, inches	B, inches	a, inches	P_Q,	P_{max},	f(a/w)	K_Q
			Longitudinal (L-T)				
6-1	2.5	1.25	1.125	17,500	17,500	8.34	73.9
6-2	2.5	1.25	1.132	17,700	17,700	8.37	74.9
6-3	2.5	1.25	1.129	19,000	19,100	8.36	80.3
6-4	2.5	1.25	1.127	19,100	19,200	8.35	80.7
						Average	77.4

TABLE XLV. AXIAL LOAD FATIGUE TEST RESULTS FOR UNNOTCHED LONGITUDINAL STOA Ti-10V-2Fe-3Al ROUND BAR

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
	Room Temperature	
5-12	150	2,100
5-15	145	7,400
5-11	140	11,900
5-16	135	20,600
5-13	130	93,500
5-17	125	7,076,000
5-14	120	10,000,000 [a]
5-10	110	10,000,000 [a]
	400 F	
5-7	120	300
5-6	120	8,500
5-8	110	15,300
5-9	105	10,000,000 [a]
5-6	100	10,000,000 [a]
5-15	90	10,000,000 [a]
5-16	80	10,000,000 [a]
	800 F	
5-1	100	100
5-5	90	11,200
5-3	80	91,800
5-4	70	6,580,000
5-2	70	106,840 [b]
5-18	60	15,000,000 [a]

(a) Did not fail.

(b) Failed at thermocouple.

TABLE XLVI. AXIAL LOAD FATIGUE TEST RESULTS FOR NOTCHED (K_t = 3.0) LONGITUDINAL STOA Ti-10V-2Fe-3Al ROUND BAR

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
	Room Temperature	
5-31	70	4,000
5-32	60	6,900
5-33	50	10,200
5-34	30	37,800
5-35	20	147,100
5-60	15	8,927,000
3-36	10	10,000,000[a]
	400 F	
5-38	70	4,800
5-39	60	7,400
5-40	50	9,700
5-41	30	37,700
5-42	20	103,700
5-59	10	10,000,000[a]
	800 F	
5-45	50	8,300
5-48	40	12,700
5-46	30	23,800
5-58	20	257,000
5-47	10	11,370,000[a]

(a) Did not fail.

TABLE XLVII. SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES FOR STOA Ti-10Fe-2V-3Al ALLOY BAR

Specimen Number	Stress, ksi	Temperature, F	Hours to Indicated Creep Deformation, percent					Initial Strain, percent	Rupture Time, hours	Elongation in 2 Inches, percent	Reduction of Area, percent	Minimum Creep Rate, percent
			0.1	0.2	0.5	1.0	2.0					
3-1	105	700	--	--	--	--	--	--	On loading	12.9	68.3	--
3-3	90	700	0.1	0.2	0.8	3.0	7.0	1.228	169.6	25.2	67.1	0.074
3-6	50	700	1.5	4.0	47	152	930	0.543	1605.2[a]	2.935	--	0.00053
3-8	25	700	30	95	1165	4500[b]	--	0.098	1320.2[a]	0.616	--	0.00015
3-2	55	900	0.01	0.03	0.08	0.15	0.32	0.807	2.0	34.3	89.0	6.0
3-4	25	900	0.15	0.4	1.65	4.6	10.5	0.313	131.4	59.5	94.3	0.13
3-5	10	900	2.2	5.6	27	82	210	0.068	2306.2	161.0	98.0	0.008[a]
3-7	2.5	900	28	173	960	2500[b]	--	0.024	1319.9[a]	0.641	--	0.00033

(a) Test discontinued.

(b) Estimated.

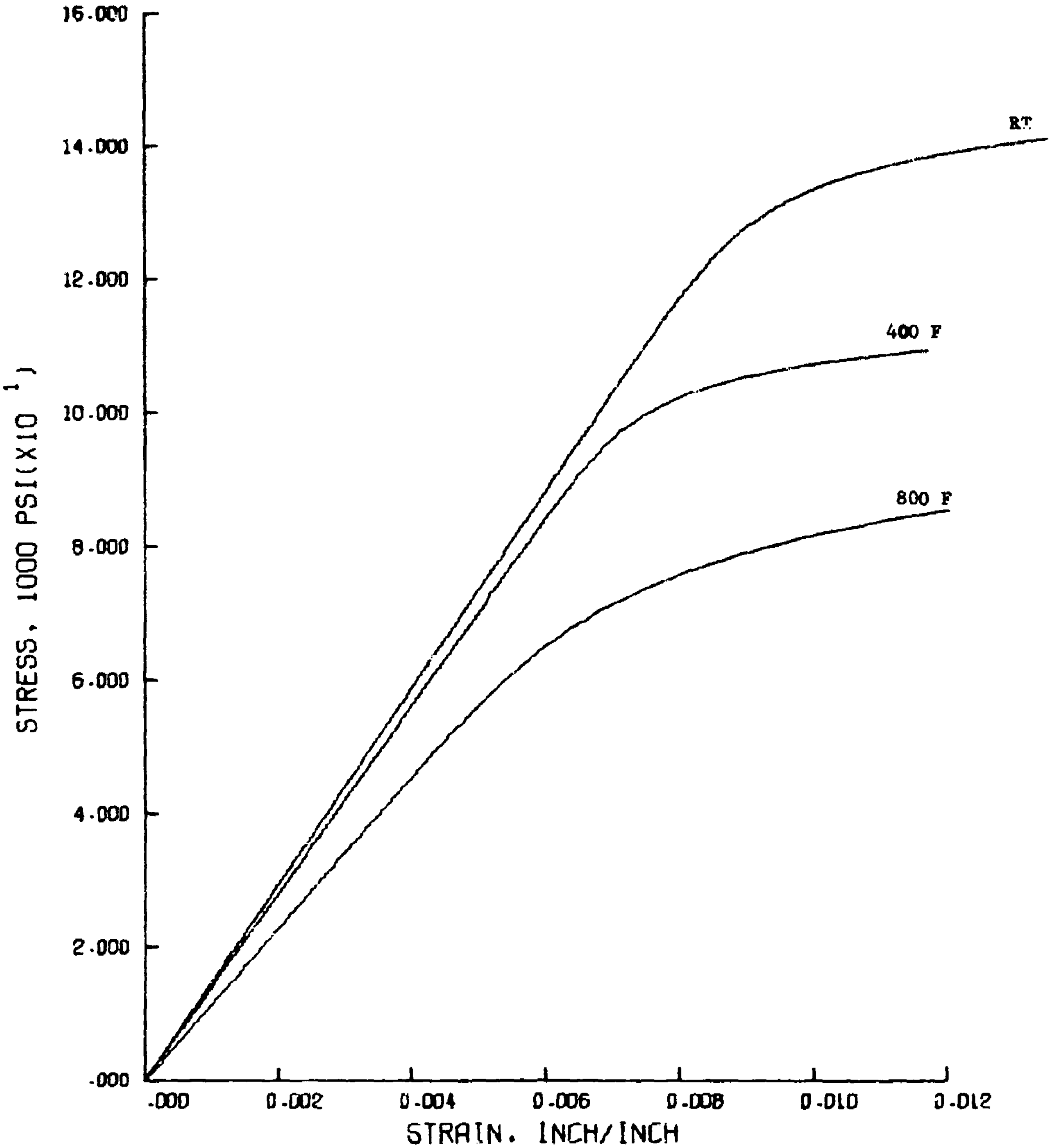

FIGURE 57. TYPICAL TENSILE LONGITUDINAL STRESS-STRAIN CURVES AT TEMPERATURE FOR STOA Ti-10V-2Fe-3Al ALLOY ROUND BAR

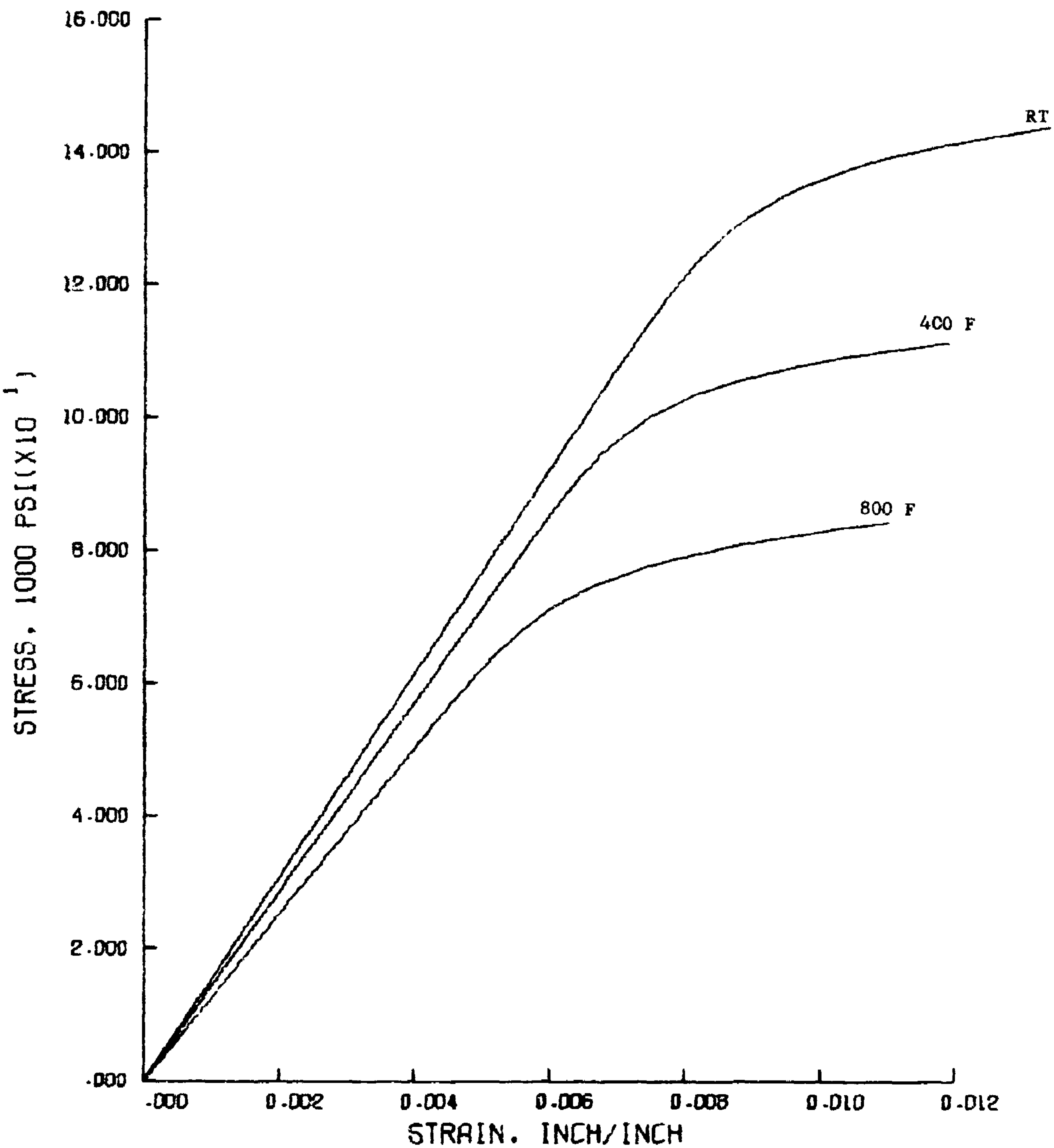

FIGURE 58. TYPICAL COMPRESSIVE LONGITUDINAL STRESS-STRAIN CURVES AT TEMPERATURE FOR STOA Ti-10V-2Fe-3Al ALLOY ROUND BAR

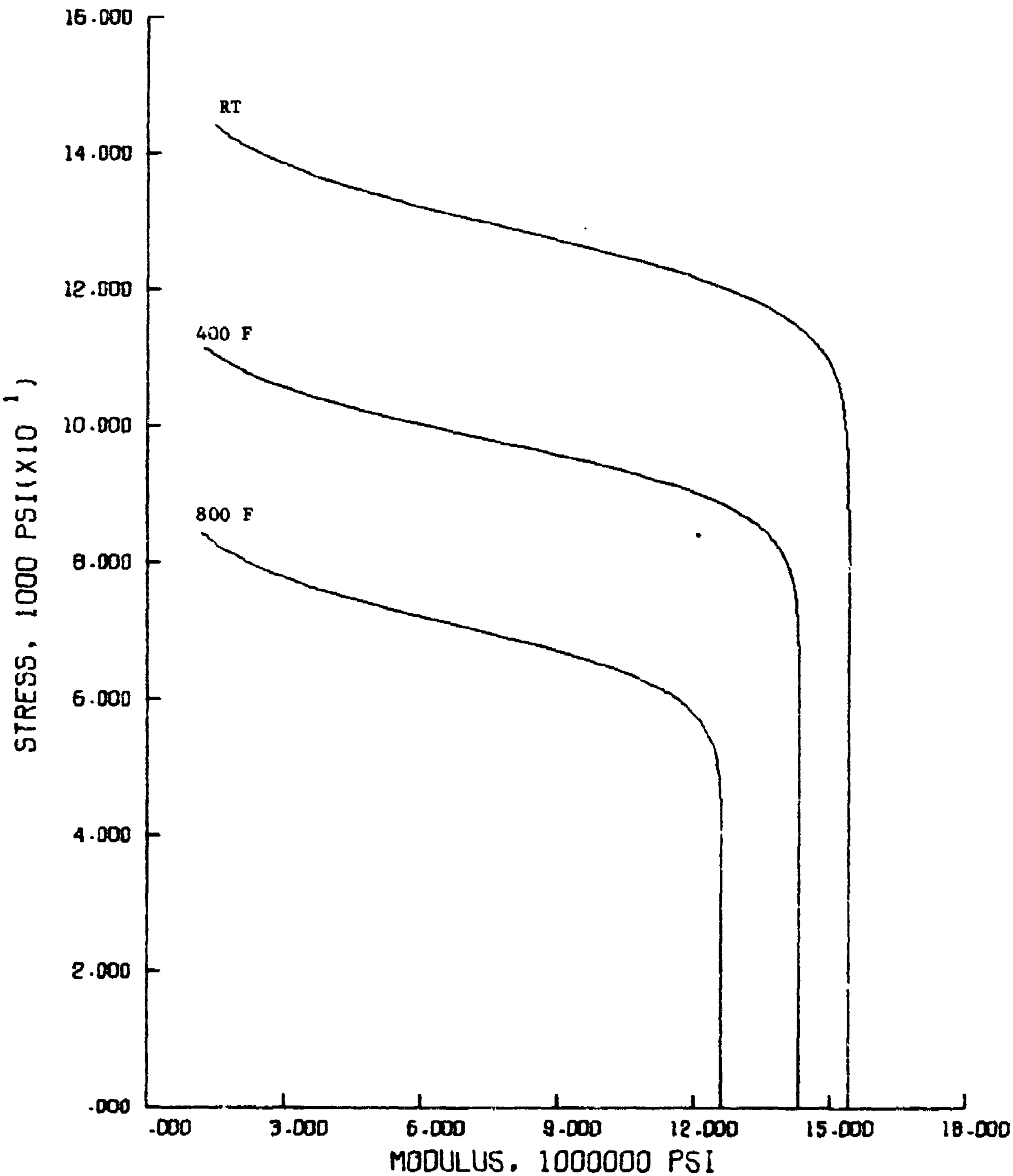

FIGURE 59. TYPICAL COMPRESSIVE LONGITUDINAL TANGENT-MODULUS CURVES AT TEMPERATURE FOR STOA Ti-10V-2Fe-3Al ALLOY ROUND BAR

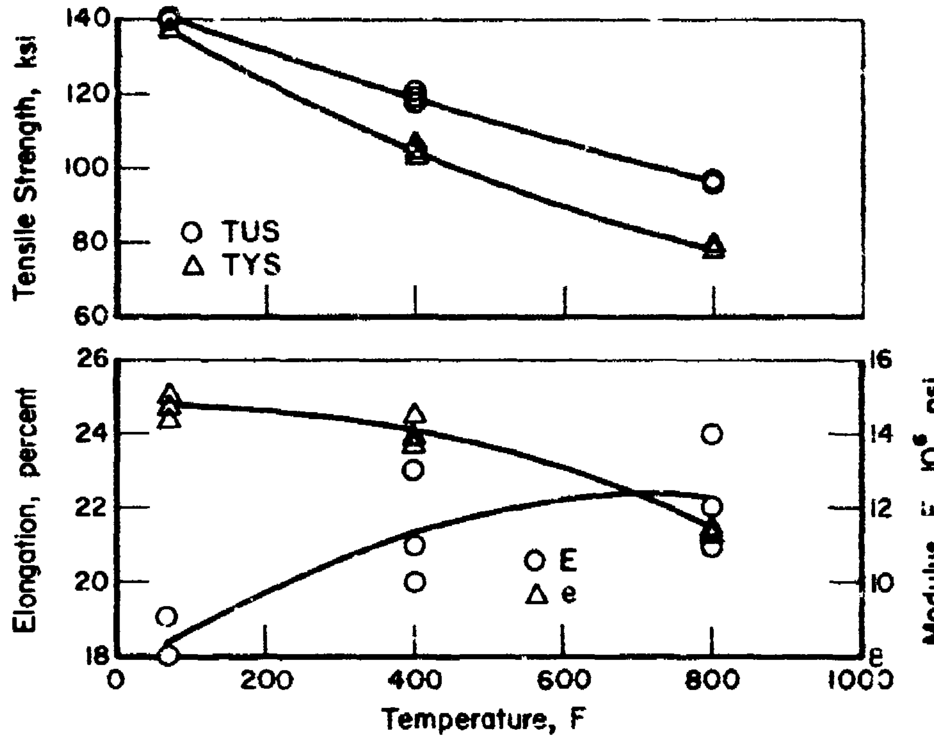

FIGURE 60. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF STOA Ti-10V-2Fe-3Al ROUND BAR

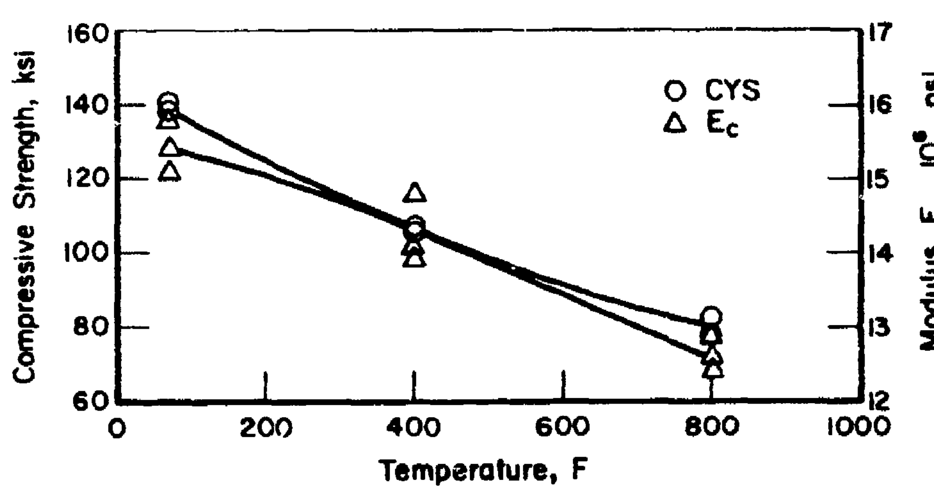

FIGURE 61. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF STOA Ti-10V-2Fe-3Al ROUND BAR

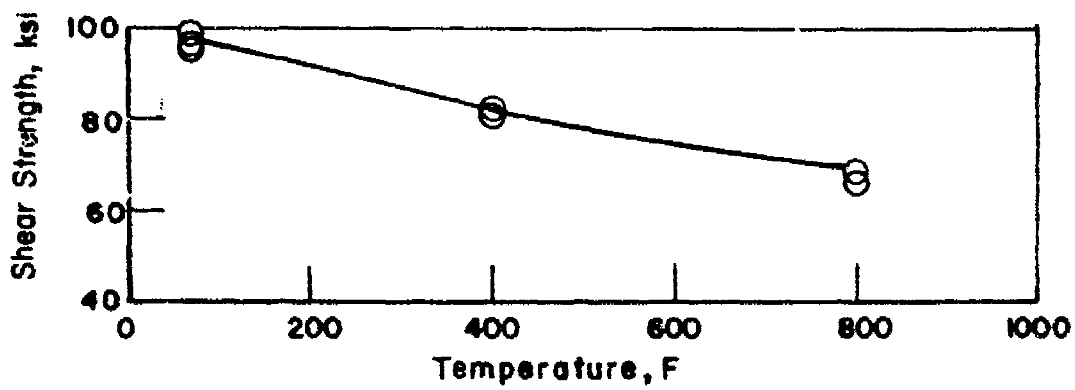

FIGURE 62. EFFECT OF TEMPERATURE ON THE SHEAR PROPERTIES OF STOA Ti-10V-2Fe-3Al ROUND BAR

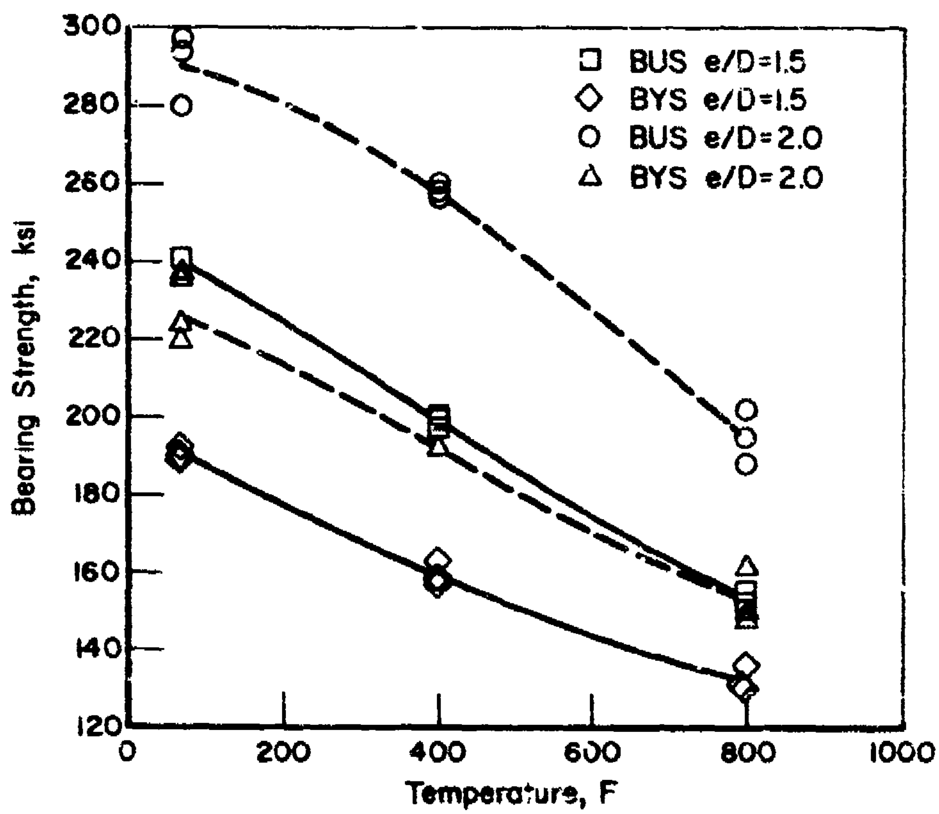

FIGURE 63. EFFECT OF TEMPERATURE ON THE BEARING PROPERTIES OF STOA Ti-10V-2Fe-3Al ROUND BAR

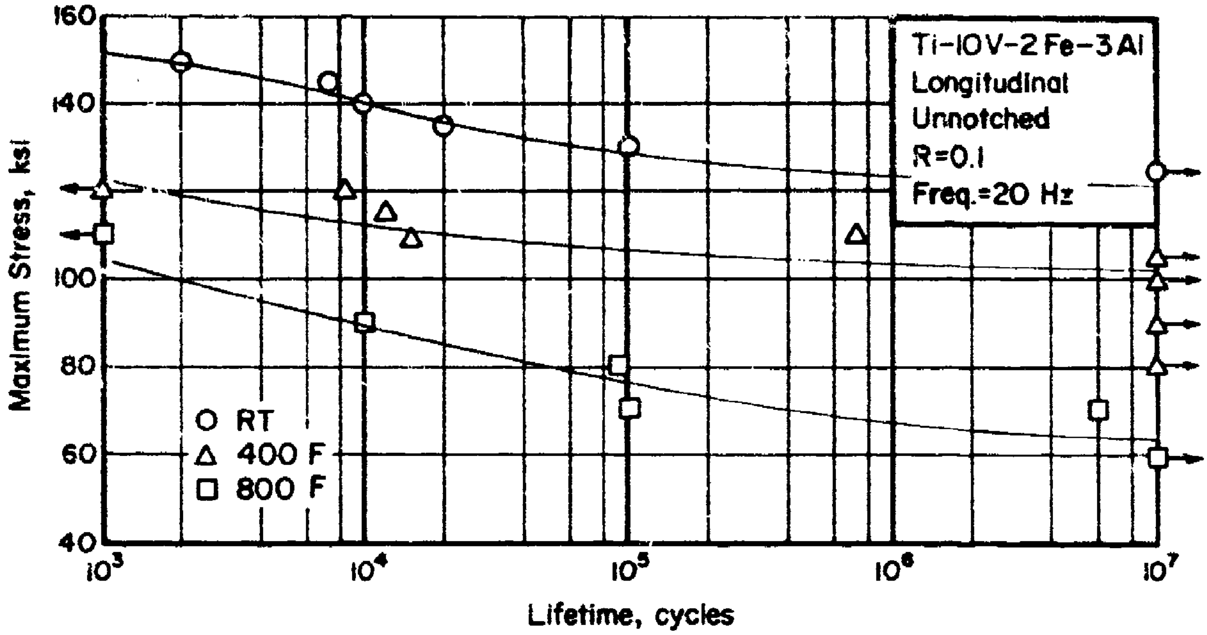

FIGURE 64. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED STOA Ti-10V-2Fe-3Al ROUND BAR

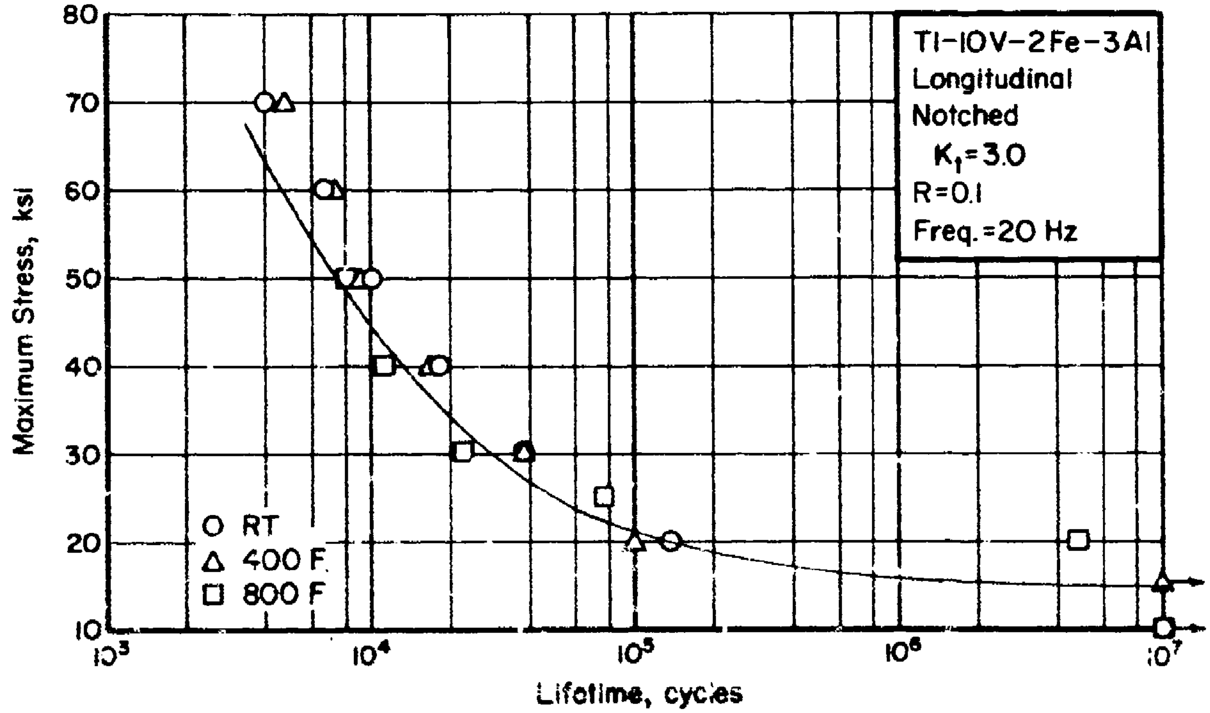

FIGURE 65. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) STOA Ti-10V-2Fe-3Al ROUND BAR

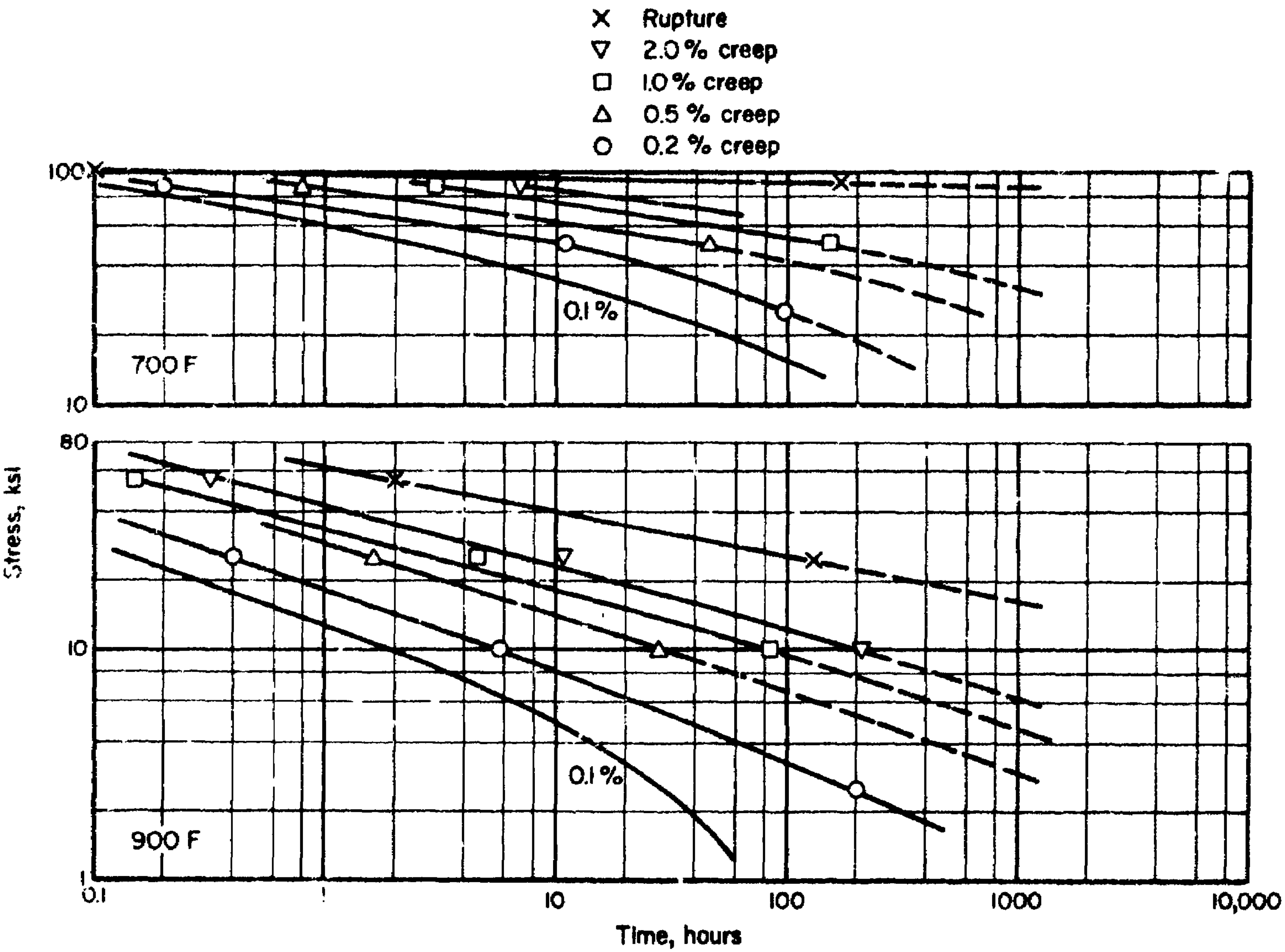

FIGURE 66. STRESS RUPTURE AND PLASTIC DEFORMATION CURVES FOR STOA Ti-10V-2Fe-3Al ALLOY ROUND BAR

Superplastically Formed Ti-6Al-4V Alloy

Material Description

The material used for this evaluation was Ti-6Al-4V superplastically formed as described in AFML-TR-75-62, "Superplastic Forming of Titanium Structures". Two nacelle forward center beam frames resulting from the program described in AFML-TR-75-62 were supplied by the Air Force. Extensive information regarding the material, forming processes, and material properties may be found in the AFML Technical Report.

Processing and Heat Treating

A photograph of the formed frame is shown in Figure 67. As can be seen from this figure, the area of flat material from which to section specimens was limited. Also it was discovered that the thickness varied in the available flat areas and it was necessary to surface grind the specimens obtained. Only tensile, compression, and fatigue specimens were available from the material.

Test Results

Tension. Results of tensile tests at room temperature, 400 F, and 800 F are given in Table XLVIII. Typical stress-strain curves at temperature are shown in Figure 68. Effect-of-temperature curves are presented in Figure 71.

Compression. Results of compression tests at room temperature, 400 F, and 800 F are shown in Table XLIX. Typical stress-strain and tangent-modulus curves at temperature are presented in Figures 69 and 70. Effect-of-temperature curves are presented in Figure 72.

Fatigue. Results of unnotched and notched fatigue tests at room temperature and 400 F are shown in Tables L and LI. S-N curves are presented in Figures 73 and 74.

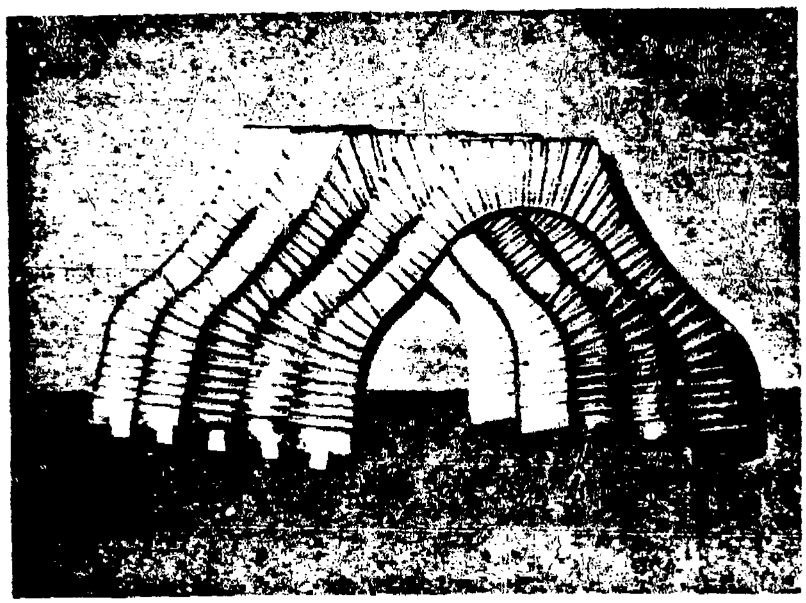

FIGURE 67. PHOTOGRAPH OF SUPERPLASTICALLY
FORMED Ti-6Al-4V FRAME

TABLE XLVIII. RESULTS OF TENSILE TESTS FOR SUPERPLASTICALLY FORMED Ti-6Al-4V ALLOY

Specimen Number		Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 1 Inch, percent	Tensile Modulus, 10^3 ksi
			Room Temperature		
1-1		140.0	126.5	15	18.4
1-2		129.8	128.2	16	17.1
	Average	139.9	127.3	15.5	17.7
			400 F		
1-3		111.7	92.7	9(a)	13.5
1-4		109.8	90.8	14	16.5
	Average	110.7	91.7	11.5	15.0
			800 F		
1-5		92.8	75.1	12	15.0
1-6		92.8	67.0	8(a)	16.8
	Average	92.8	71.1	10	15.9

(a) Failed at gage mark.

TABLE XLIX. RESULTS OF COMPRESSION TESTS FOR SUPERPLASTICALLY FORMED Ti-6Al-4V ALLOY

Specimen Number		0.2 Percent Offset Yield Strength, ksi	Compression Modulus, 10^3 ksi
		Room Temperature	
2-1		125.2	18.0
2-2		120.1	16.8
	Average	122.7	17.4
		400 F	
2-3		100.7	14.0
2-4		110.8	15.1
	Average	105.7	14.6
		800 F	
2-5		70.2	15.1
2-6		70.4	13.5
	Average	70.3	14.3

TABLE L. AXIAL LOAD FATIGUE TEST RESULTS FOR UNNOTCHED SUPERPLASTICALLY FORMED Ti-6Al-4V ALLOY

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
	Room Temperature	
5-1	100	23,800
5-2	90	20,000
5-3	80	28,500
5-4	70	52,200
5-5	60	77,100
5-7	50	223,700
5-6	40	5,060,000
	400 F	
5-8	80	18,000
5-9	70	36,500
5-10	60	38,700
5-11	50	68,600
5-12	40	102,000
5-13	30	187,000

TABLE LI. AXIAL LOAD FATIGUE TEST RESULTS FOR NOTCHED (K_t = 3.0) SUPERPLASTICALLY FORMED Ti-6Al-4V ALLOY

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
	Room Temperature	
5-34	60	18,700
5-33	50	27,200
5-31	40	45,000
5-35	35	129,600
5-32	30	115,400
5-36	25	372,600
5-37	20	1,360,000 (a)
5-38	15	10,020,000 (a)
	400 F	
5-43	60	14,000
5-44	50	24,800
5-39	40	45,300
5-40	30	129,500
5-41	25	342,200 (a)
5-42	20	10,000,000 (a)

(a) Did not fail.

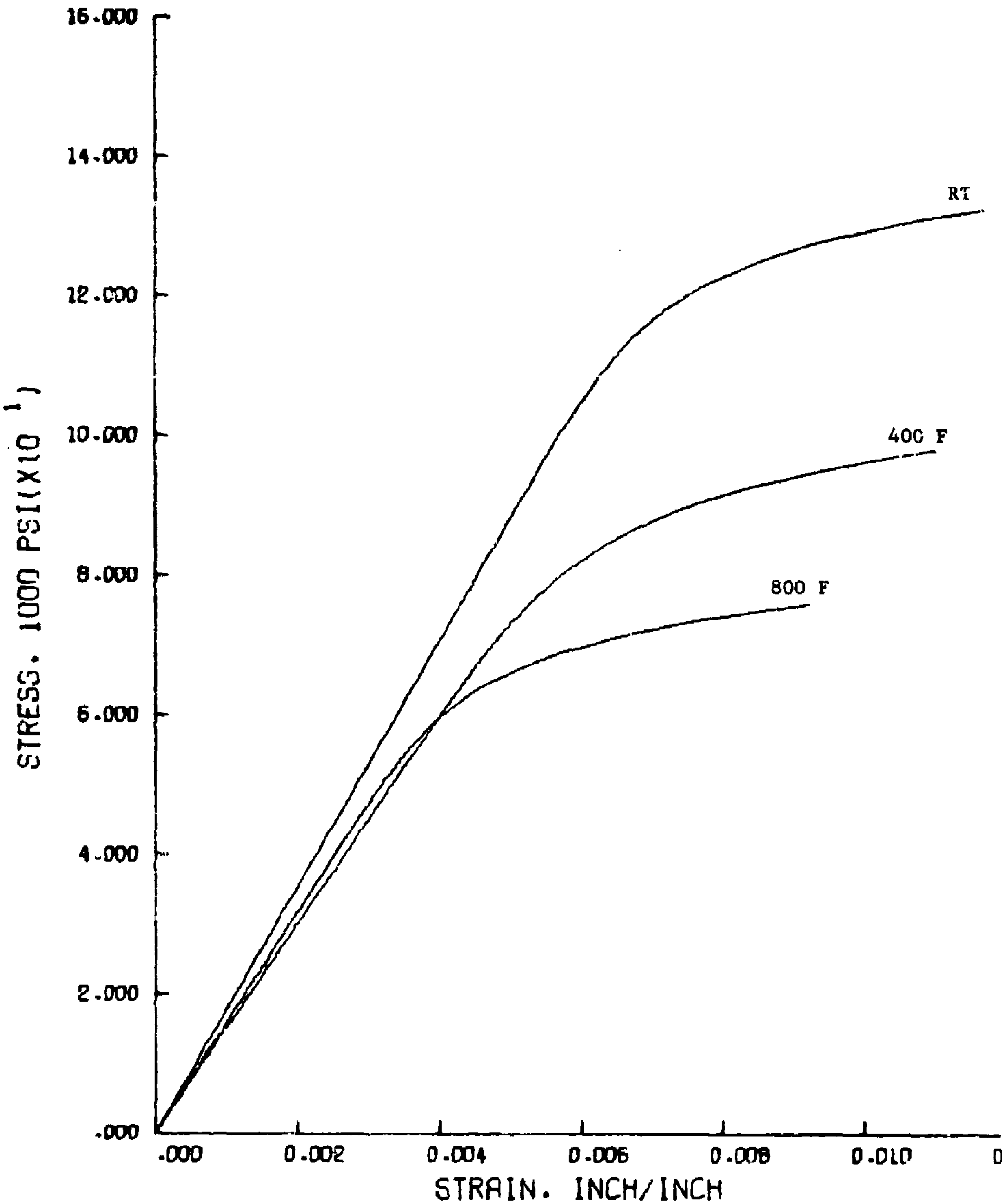

FIGURE 68. TYPICAL TENSILE STRESS-STRAIN CURVES AT TEMPERATURE FOR SUPERPLASTICALLY FORMED Ti-6Al-4V ALLOY

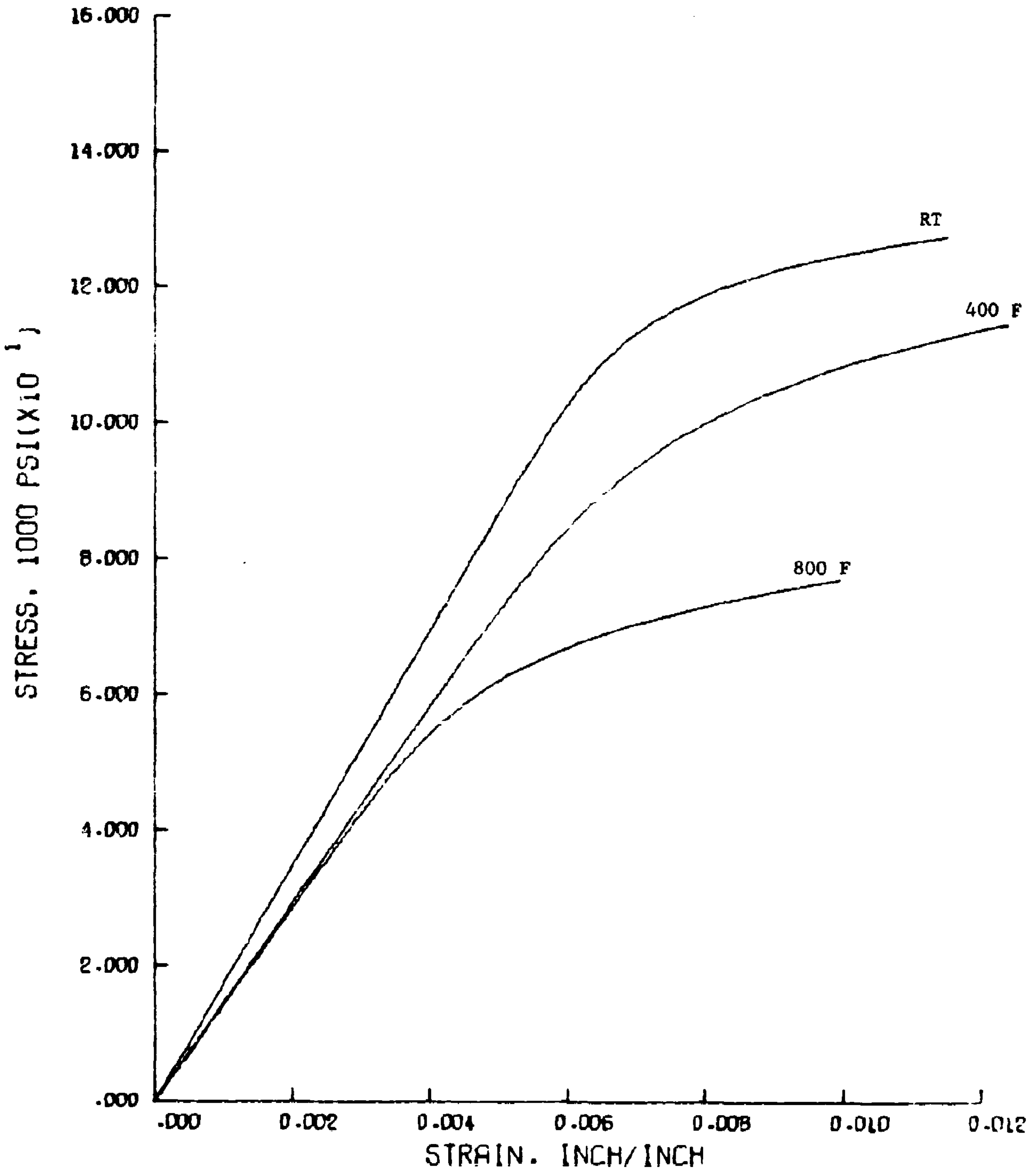

FIGURE 69. TYPICAL COMPRESSIVE STRESS-STRAIN CURVES AT TEMPERATURE FOR SUPERPLASTICALLY FORMED Ti-6Al-4V ALLOY

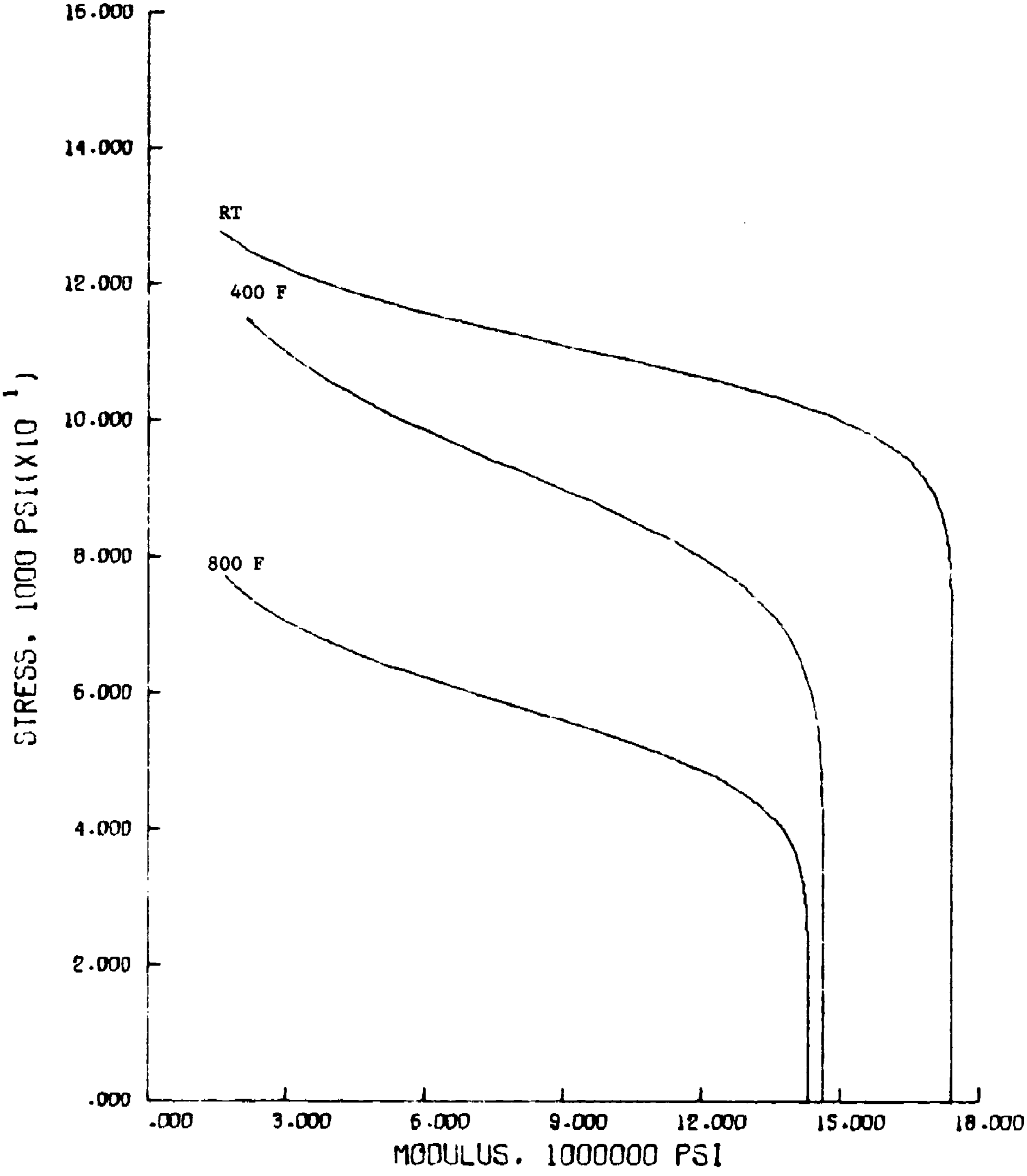

FIGURE 70. TYPICAL COMPRESSIVE TANGENT-MODULUS CURVES AT TEMPERATURE FOR SUPERPLASTICALLY FORMED Ti-6Al-4V ALLOY

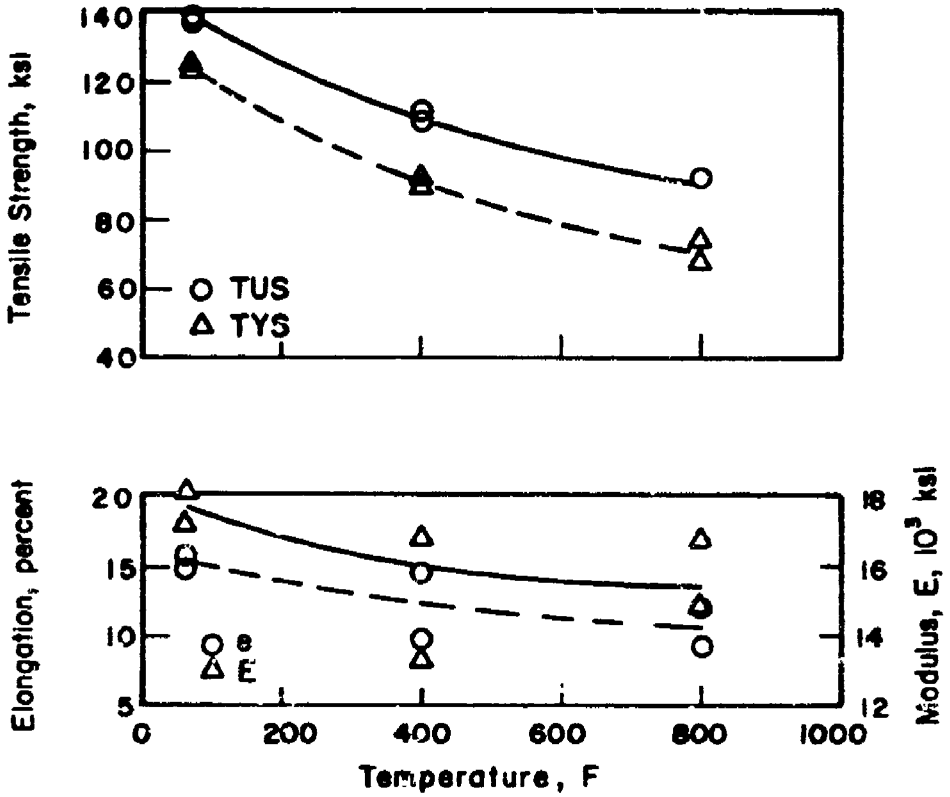

FIGURE 71. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF SUPERPLASTICALLY FORMED Ti-6Al-4V ALLOY

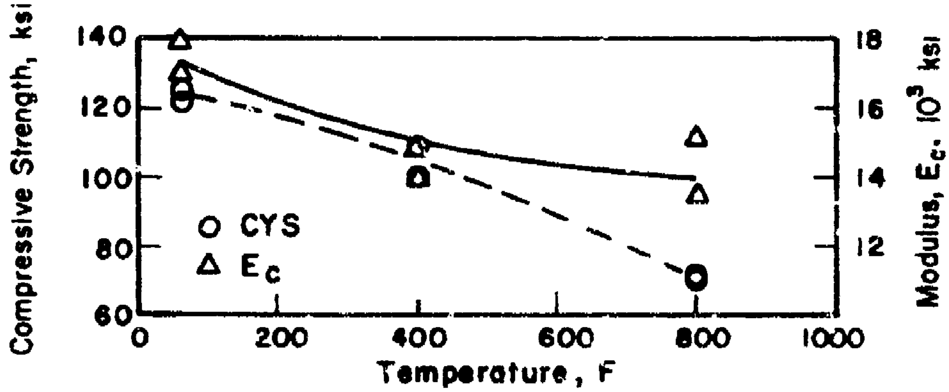

FIGURE 72. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF SUPERPLASTICALLY FORMED Ti-6Al-4V ALLOY

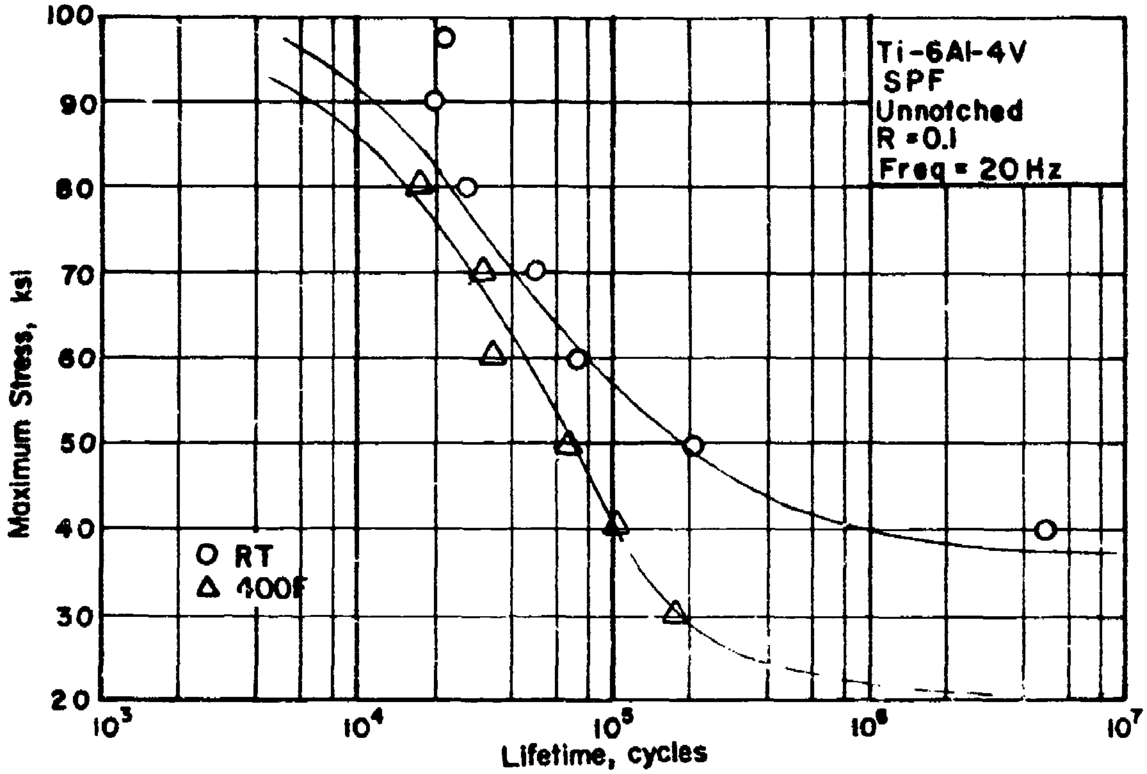

FIGURE 73. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED SUPERPLASTICALLY FORMED Ti-6Al-4V ALLOY

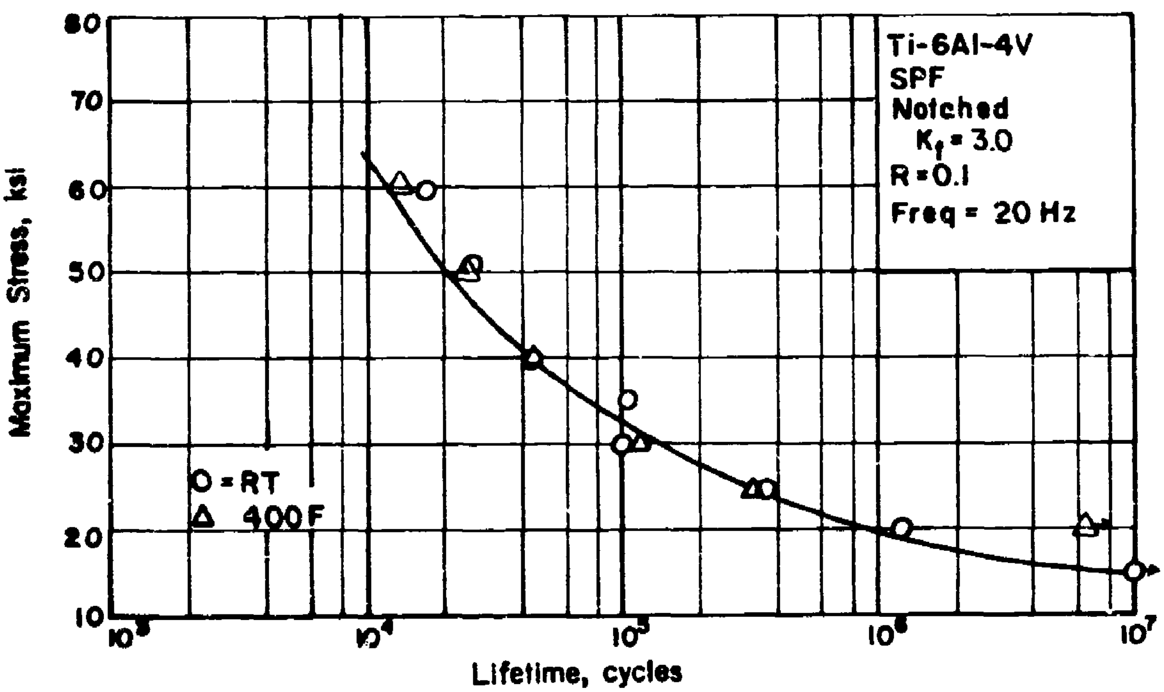

FIGURE 74. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) SUPERPLASTICALLY FORMED Ti-6Al-4V ALLOY

7175-T76511 Aluminum Alloy Extrusions

Material Description

This aluminum alloy is a development of Alcoa and is primarily a higher purity modification of Alloy 7075. It was developed to provide improvements in mechanical properties, fracture toughness, and stress-corrosion resistance over 7075. The material evaluated on this program was an extrusion supplied by the Air Force. It was about 2 inches thick by 24 inches wide by about 28 inches long.

Composition limits for 7175 are as previously described for the 7175-T73511 extrusion.

Processing and Heat Treating

The alloy was evaluated in the -T76511 temper. Specimens were sectioned as shown in the preceding 7175-T73511 section of this report.

Test Results

Tension. Results of tensile tests for longitudinal and transverse specimens at room temperature, 250 F, and 350 F are given in Table LII. Typical stress-strain curves at temperature are shown in Figures 75 and 76. Effect-of-temperature curves are presented in Figure 81.

Compression. Results of longitudinal and transverse tests at room temperature, 250 F, and 350 F are shown in Table LIII. Typical stress-strain and tangent-modulus curves are presented in Figures 77 through 80. Effect-of-temperature curves are presented in Figure 83.

Shear. Results of longitudinal and transverse pin shear tests at room temperature, 250 F, and 350 F are shown in Table LIV. Effect-of-temperature curves are presented in Figure 83.

Bearing. Bearing test results for longitudinal and transverse specimens at e/D = 1.5 and e/D = 2.0 at room temperature, 250 F, and 350 F are given in Table LV. Effect-of-temperature curves are shown in Figure 84.

Impact. Results of Charpy tests for longitudinal and transverse specimens at room temperature are given in Table LVI.

Fracture Toughness. Results of compact tension type tests for longitudinal and transverse tests at room temperature are presented in Table LVII. The K_Q values are valid K_{Ic} values per ASTM E399.

Fatigue. Axial load fatigue test results for transverse specimens (unnotched and notched) at room temperature, 250 F, and 350 F are given in Tables LVIII and LIX. S-N curves are presented in Figures 85 and 86.

Creep and Stress Rupture. No creep evaluation was made on this aluminum alloy.

Stress Corrosion. Specimens were tested as described in the experimental procedures section of this report. No cracks or failures occurred in the test duration.

Thermal Expansion. The coefficient of thermal expansion for this alloy is 12.5×10^{-6} in/in/F (70 to 212 F).

Density. The density of this material is 0.101 lbs/in^3.

TABLE LII. RESULTS OF TENSILE TESTS FOR 7175-T76511 ALUMINUM ALLOY EXTRUSIONS

Specimen Number		Tensile Ultimate Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 1 Inch, percent	Reduction in Area, percent	Tensile Modulus, 10^3 ksi
			Longitudinal at Room Temperature			
1L-1		80.0	68.9	12.0	35.9	10.7
1L-2		80.0	69.3	12.0	34.6	10.3
1L-3		81.1	69.0	12.5	33.2	10.5
	Average	80.4	69.1	12.2	34.6	10.5
			Transverse at Room Temperature			
1T-1		79.4	67.6	11.0	29.6	10.7
1T-2		77.6	67.0	11.0	34.2	10.7
1T-3		79.1	69.1	12.0	20.2	10.7
	Average	78.7	67.9	11.3	28.0	10.7
			Longitudinal at 250 F			
1L-4		66.3	63.0	25.0	51.2	9.9
1L-5		66.3	61.0	21.0	51.8	10.0
1L-6		65.4	63.0	21.0	52.5	10.1
	Average	66.0	62.3	22.3	51.8	10.0
			Transverse at 250 F			
1T-4		65.4	63.3	18.0	38.6	10.3
1T-5		66.6	62.4	23.0	40.0	10.1
1T-6		65.0	59.9	21.0	49.1	10.3
	Average	65.7	61.9	20.7	42.6	10.3
			Longitudinal at 350 F			
1L-7		48.0	45.5	28.0	70.2	8.5
1L-8		50.1	44.2	31.0	67.7	8.0
1L-9		47.1	41.0	30.0	69.3	9.0
	Average	48.4	43.6	29.7	69.1	8.5
			Transverse at 350 F			
1T-7		49.2	40.9	27.0	55.6	8.5
1T-8		48.2	40.0	30.0	50.8	8.7
1T-9		49.0	42.2	26.0	52.7	8.6
	Average	48.8	41.0	27.7	53.0	8.6

TABLE LIII. RESULTS OF COMPRESSION TESTS FOR 7175-T76511 ALUMINUM ALLOY EXTRUSIONS

Specimen Number		0.2 Percent Offset Yield Strength, ksi	Compressive Modulus, 10^3 ksi
		Longitudinal at Room Temperature	
2L-1		72.0	10.5
2L-2		71.9	10.7
2L-3		72.0	10.5
	Average	72.0	10.6
		Transverse at Room Temperature	
2T-1		73.6	10.6
2T-2		72.9	11.0
2T-3		74.0	10.3
	Average	73.5	10.6
		Longitudinal at 250 F	
2L-4		64.6	10.1
2L-5		65.2	9.9
2L-6		65.8	10.0
	Average	65.2	10.0
		Transverse at 250 F	
2T-4		65.9	10.0
2T-5		67.2	10.0
2T-6		66.5	9.5
	Average	66.5	9.8
		Longitudinal at 350 F	
2L-7		52.8	9.7
2L-8		50.1	9.3
2L-9		53.6	9.0
	Average	52.1	9.3
		Transverse at 350 F	
2T-7		54.0	8.9
2T-8		50.6	10.0
2T-9		51.7	9.2
	Average	52.1	9.3

TABLE LIV. RESULTS OF SHEAR TESTS FOR 7175-T76511 ALUMINUM ALLOY EXTRUSIONS

Specimen Number		Shear Ultimate Strength, ksi
Longitudinal at Room Temperature		
4L-1		46.7
4L-2		48.6
4L-3		47.7
	Average	47.7
Transverse at Room Temperature		
4T-1		45.8
4T-2		47.0
4T-3		48.6
	Average	47.1
Longitudinal at 250 F		
4L-4		39.0
4L-5		39.0
4L-6		38.0
	Average	38.7
Transverse at 250 F		
4T-4		38.6
4T-5		38.9
4T-6		38.9
	Average	38.8
Longitudinal at 350 F		
4L-7		30.6
4L-8		31.0
4L-9		31.0
	Average	30.9
Transverse at 350 F		
4T-7		32.6
4T-8		30.9
4T-9		31.0
	Average	31.5

TABLE LV. RESULTS OF BEARING TESTS AT e/D = 1.5 AND e/D = 2.0 FOR 7175-T76511 ALUMINUM ALLOY EXTRUSION

Specimen Number	Specimen Orientation	Bearing Ultimate Strength, ksi		Bearing Yield Strength, ksi	
		e/D = 1.5	e/D = 2.0	e/D = 1.5	e/D = 2.0
		Room Temperature			
L-1	L	120.1	157.7	93.6	112.6
L-2	L	118.3	156.2	95.0	112.6
L-3	L	116.7	158.4	47.1	112.1
	Average	118.4	157.4	95.2	112.4
T-1	T	122.1	158.9	95.0	115.0
T-2	T	120.6	160.0	96.7	110.7
T-3	T	124.8	154.6	98.0	113.8
	Average	122.5	157.8	96.6	113.2
		250 F			
L-4	L	105.3	128.4	90.0	97.7
L-5	L	105.7	129.1	89.0	97.9
L-6	L	107.8	126.4	87.0	99.0
	Average	106.3	128.0	88.7	98.2
T-4	T	100.2	130.0	87.0	100.9
T-5	T	107.7	130.0	91.6	102.7
T-6	T	109.2	130.0	86.8	105.0
		105.7	130.0	88.5	102.9
		350 F			
L-7	L	78.6	93.6	71.0	81.7
L-8	L	80.1	87.5	75.6	76.7
L-9	L	75.7	90.0	70.0	78.2
	Average	78.1	90.3	72.2	78.9
T-7	T	81.0	87.6	73.8	79.9
T-8	T	77.7	101.3	72.6	88.4
T-9	T	78.6	98.3	71.6	90.2
	Average	79.1	95.7	72.7	86.2

TABLE LVI. RESULTS OF CHARPY IMPACT TESTS AT ROOM TEMPERATURE FOR 7175-T76511 ALUMINUM ALLOY EXTRUSIONS

Specimen Number		Energy, ft/lbs
	Longitudinal	
10L-1		7.0
10L-2		9.0
10L-3		8.0
	Average	8.0
	Transverse	
10T-1		4.5
10T-2		4.5
10T-3		4.5
	Average	4.5

TABLE LVII. RESULTS OF COMPACT TENSION TYPE FRACTURE TOUGHNESS TESTS AT ROOM TEMPERATURE FOR 7175-T76511 ALUMINUM ALLOY EXTRUSIONS

Specimen Number	W, inches	B, inches	a, inches	P_Q, lbs	P_{max}, lbs	f(a/w)	K_Q
			Longitudinal (L-T)				
6L-1	2.0	1.0	0.981	3900	4000	9.33	25.7
6L-2	2.0	1.0	1.000	3915	4000	9.60	26.7
6L-3	2.0	1.0	1.020	3825	3900	9.90	26.8
						Average	26.4
			Transverse (T-L)				
6T-1	2.0	1.0	1.010	4650	4700	9.90	32.6
6T-2	2.0	1.0	1.002	4600	4800	9.60	32.6
6T-3	2.0	1.0	1.008	4775	4800	9.65	32.6
						Average	32.6

TABLE LVIII. RESULTS OF AXIAL LOAD FATIGUE TESTS FOR TRANSVERSE UNNOTCHED 7175-T76511 ALUMINUM ALLOY EXTRUSION

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
	Room Temperature	
5-1	70	2,500
5-2	60	32,600
5-4	55	51,700
5-3	50	92,000
5-5	47.5	1,062,000
5-6	45	5,762,000
5-8	42.5	10,000,000[a]
5-7	40	10,000,000[a]
	250 F	
5-16	60	23,300
5-15	55	30,000
5-8	50	56,600
5-9	50	61,600
5-10	45	78,900
5-11	40	143,200
5-12	35	207,100
5-14	30	10,000,000[a]
	350 F	
5-17	55	100
5-22	50	7,300
5-19	45	12,900
5-18	40	25,000
5-23	35	598,000
5-25	32.5	602,100
5-26	30	1,820,000
5-27	27.5	7,666,100
5-28	25	10,000,000[a]

(a) Did not fail.

TABLE LIX. RESULTS OF AXIAL LOAD FATIGUE TESTS FOR TRANSVERSE, NOTCHED (K_t = 3.0) 7175-T76511 ALUMINUM ALLOY EXTRUSION

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
	Room Temperature	
5-34	40	6,900
5-33	35	9,900
5-31	30	56,100
5-39	30	59,100
5-35	25	47,900
5-37	25	47,100
5-32	20	93,300
5-38	17.5	133,200
5-36	15	10,000,000[a]
	250 F	
5-47	40	5,700
5-45	35	9,800
5-42	30	17,100
5-46	25	32,700
5-43	25	64,800
5-40	20	72,100
5-41	17.5	158,500
5-48	15	241,900
5-44	10	10,000,000[a]
	350 F	
5-49	35	6,400
5-50	30	12,000
5-51	25	23,800
5-52	20	40,000
5-53	15	130,200
5-54	12.5	327,400
5-55	10	10,000,000[a]
5-56	10	10,000,000[a]

(a) Did not fail.

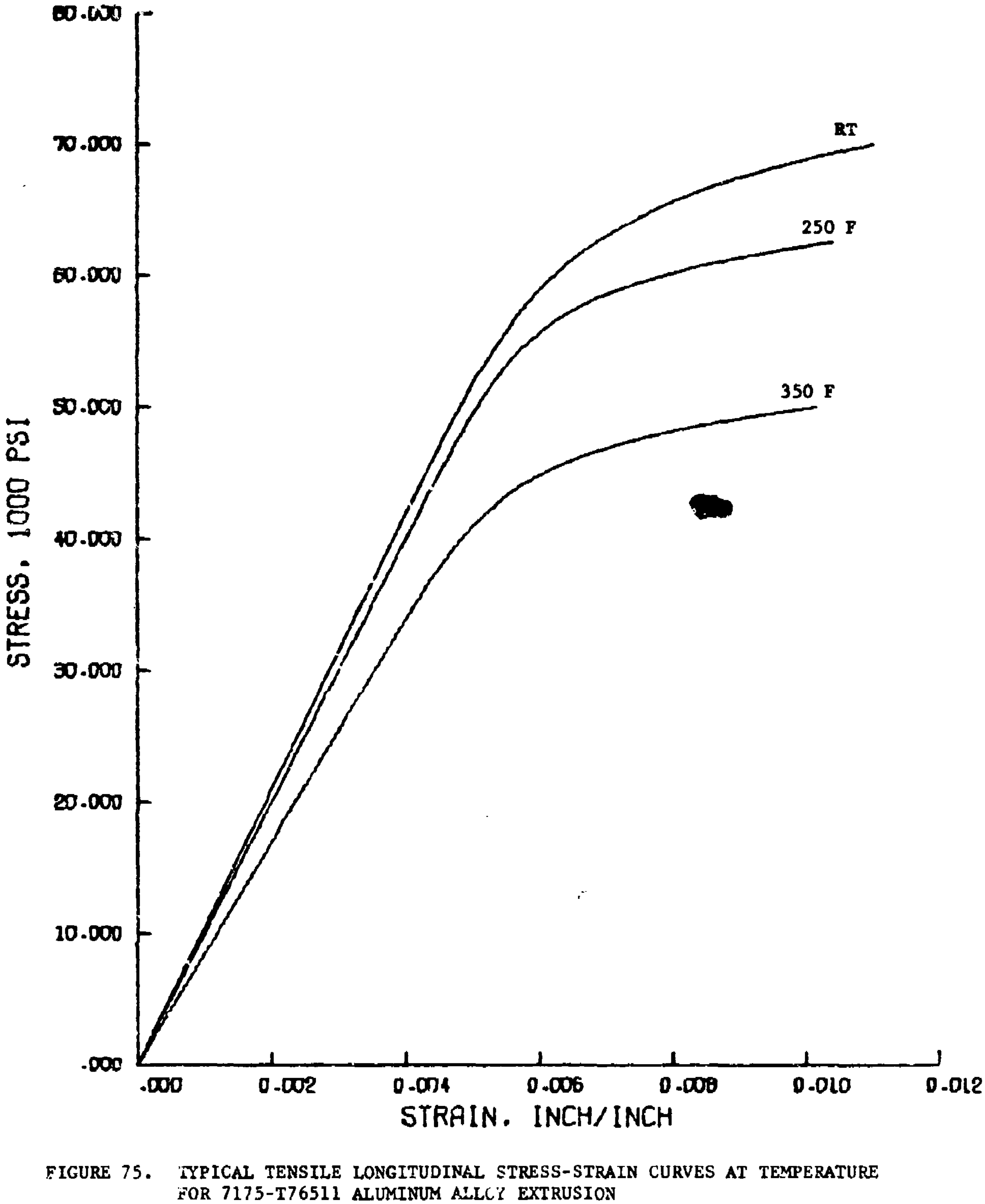

FIGURE 75. TYPICAL TENSILE LONGITUDINAL STRESS-STRAIN CURVES AT TEMPERATURE FOR 7175-T76511 ALUMINUM ALLOY EXTRUSION

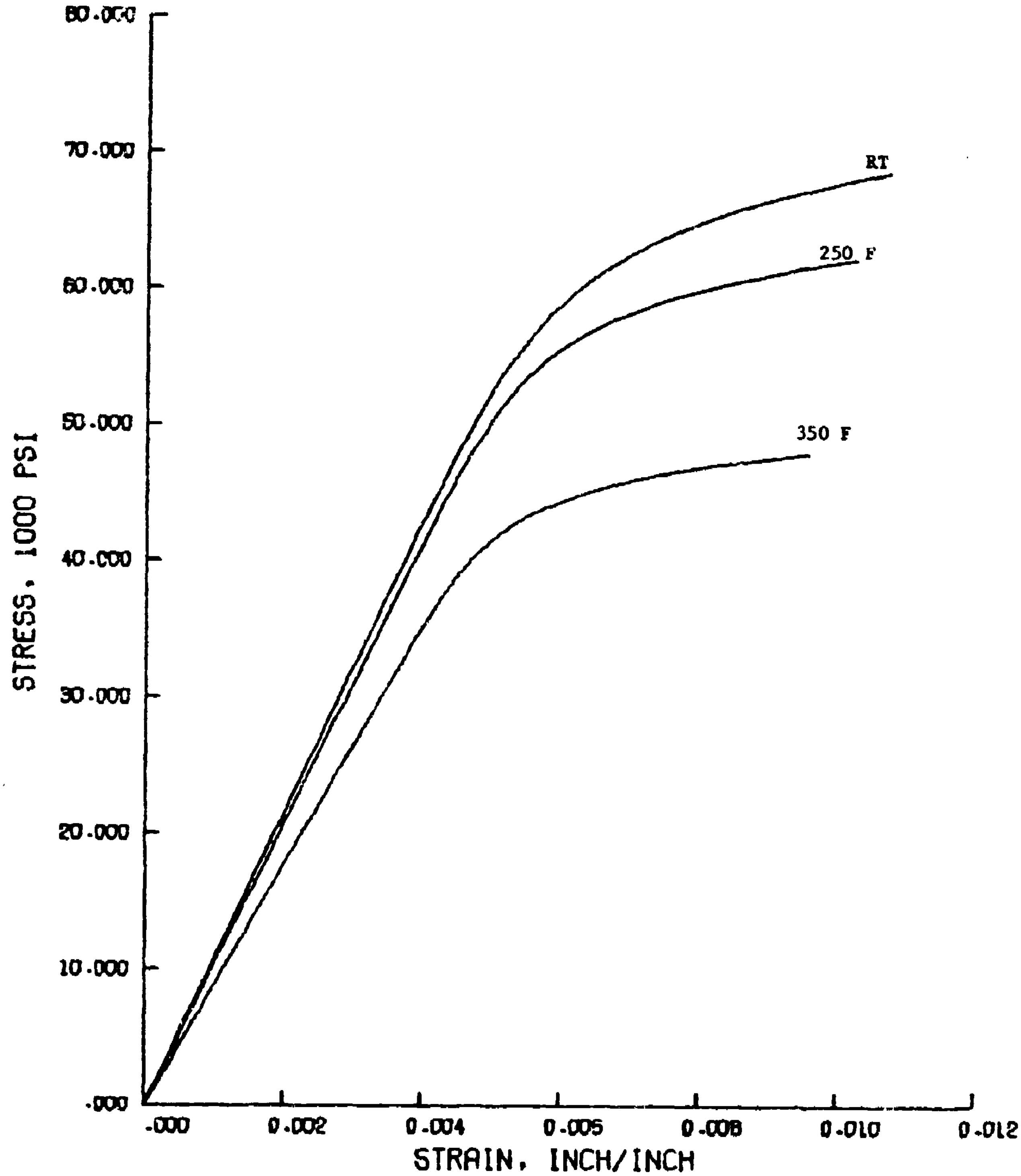

FIGURE 76. TYPICAL TENSILE TRANSVERSE STRESS-STRAIN CURVES AT TEMPERATURE FOR 7175-T76511 ALUMINUM ALLOY EXTRUSION

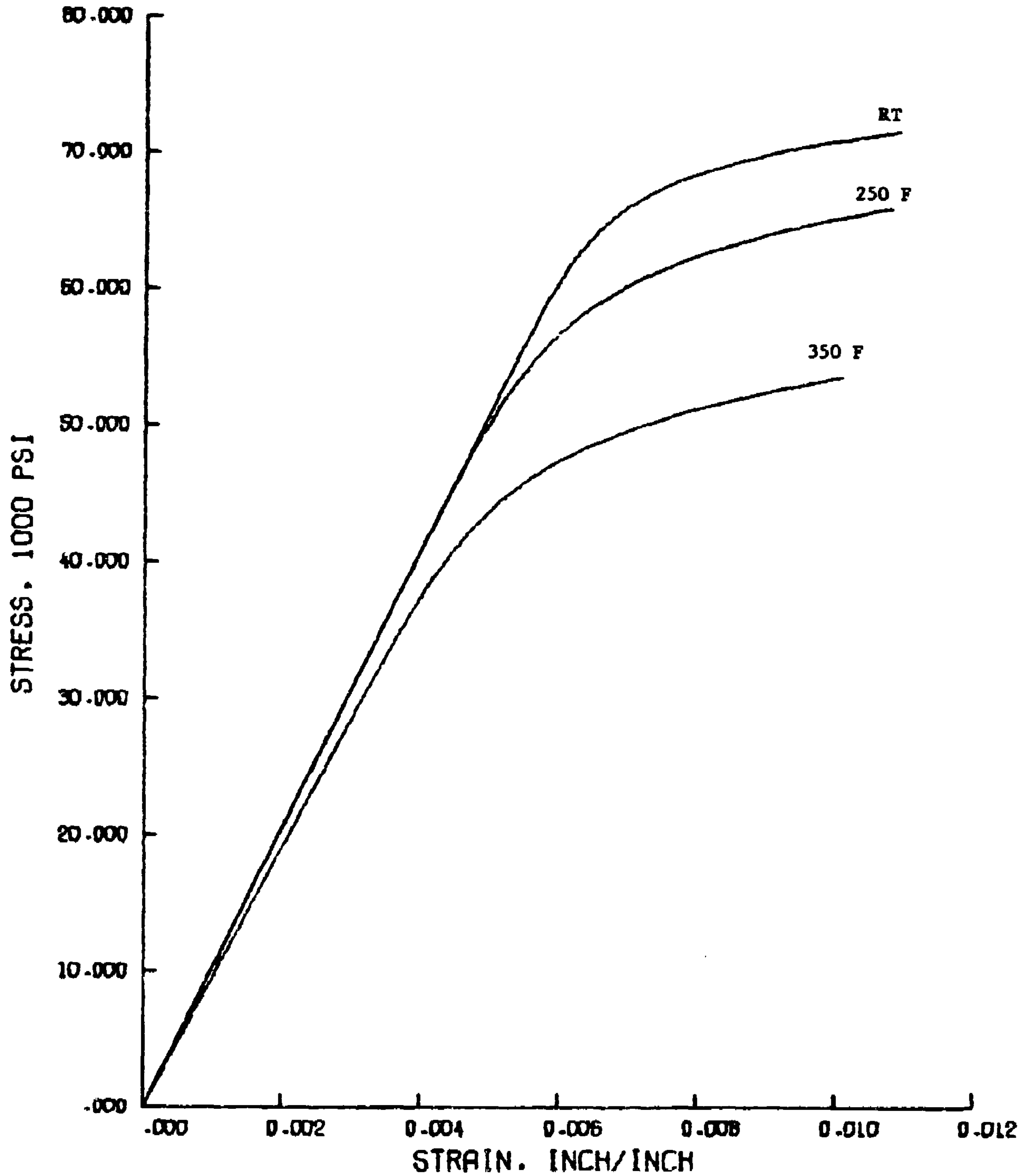

FIGURE 77. TYPICAL COMPRESSIVE LONGITUDINAL STRESS-STRAIN CURVES AT TEMPERATURE FOR 7175-T76511 ALUMINUM ALLOY EXTRUSIONS

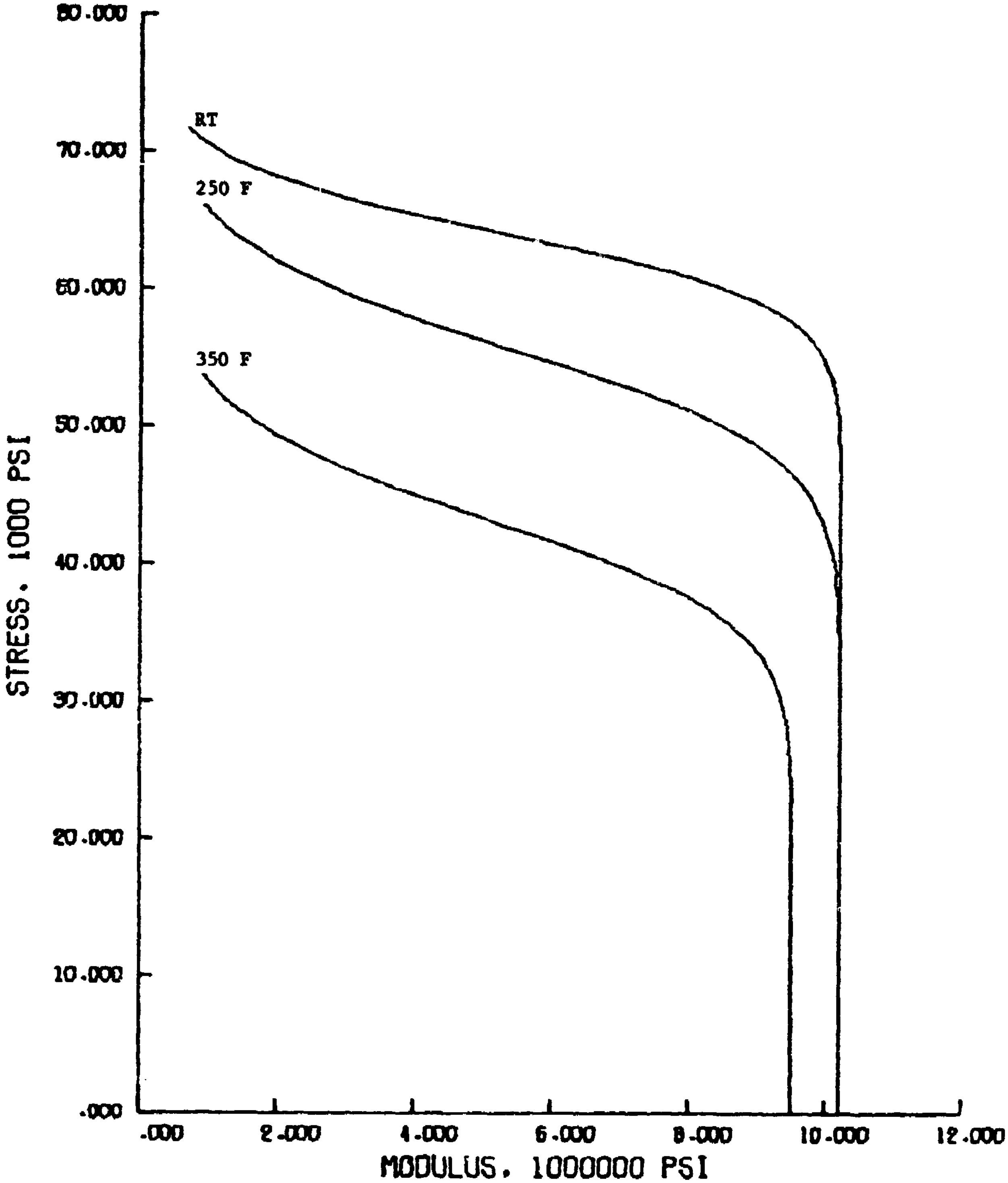

FIGURE 78. TYPICAL COMPRESSIVE LONGITUDINAL TANGENT-MODULUS CURVES AT TEMPERATURE FOR 7175-T76511 ALUMINUM ALLOY EXTRUSIONS

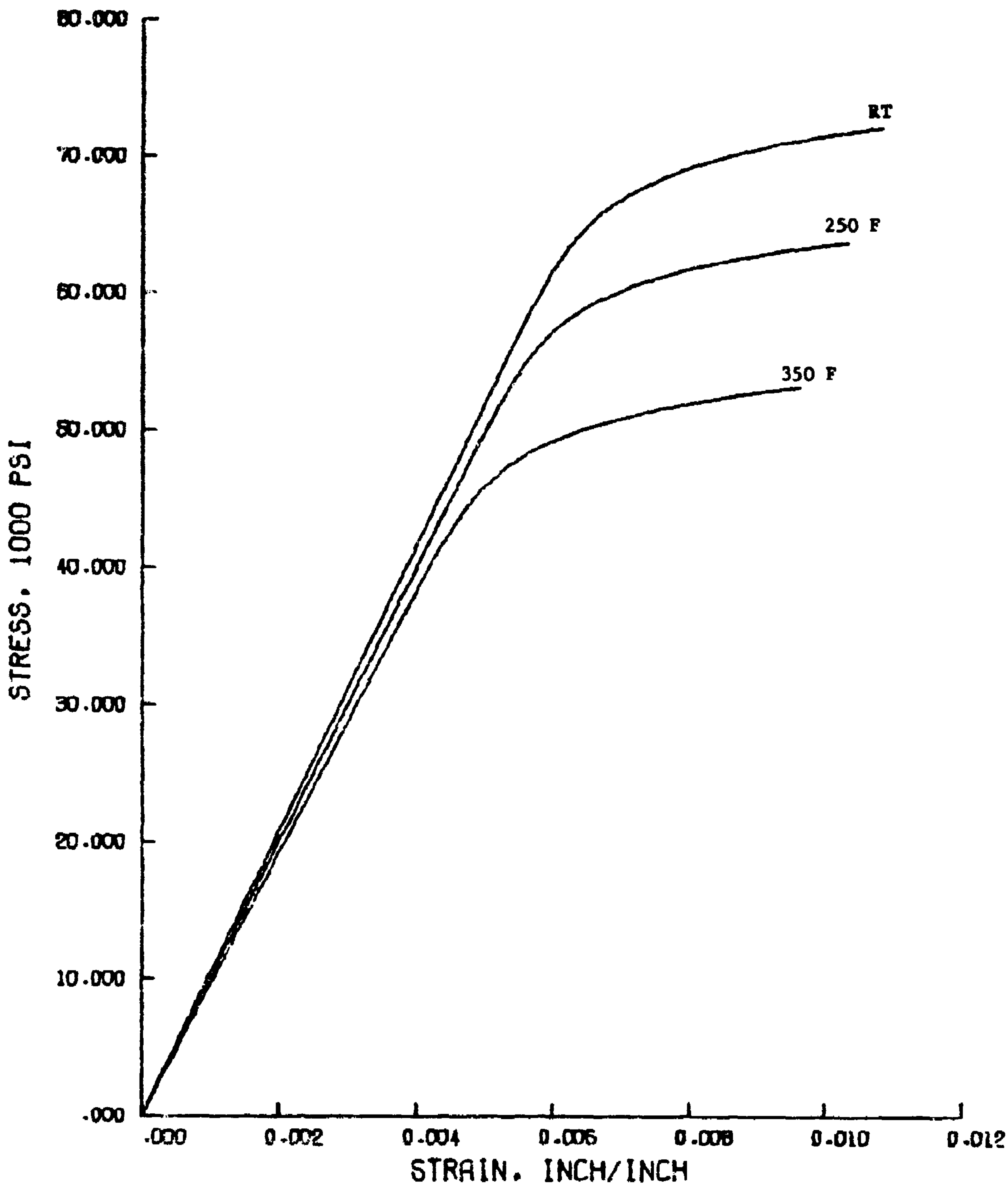

FIGURE 79. TYPICAL COMPRESSIVE TRANSVERSE STRESS-STRAIN CURVES AT TEMPERATURE FOR 7175-T76511 ALUMINUM ALLOY EXTRUSIONS

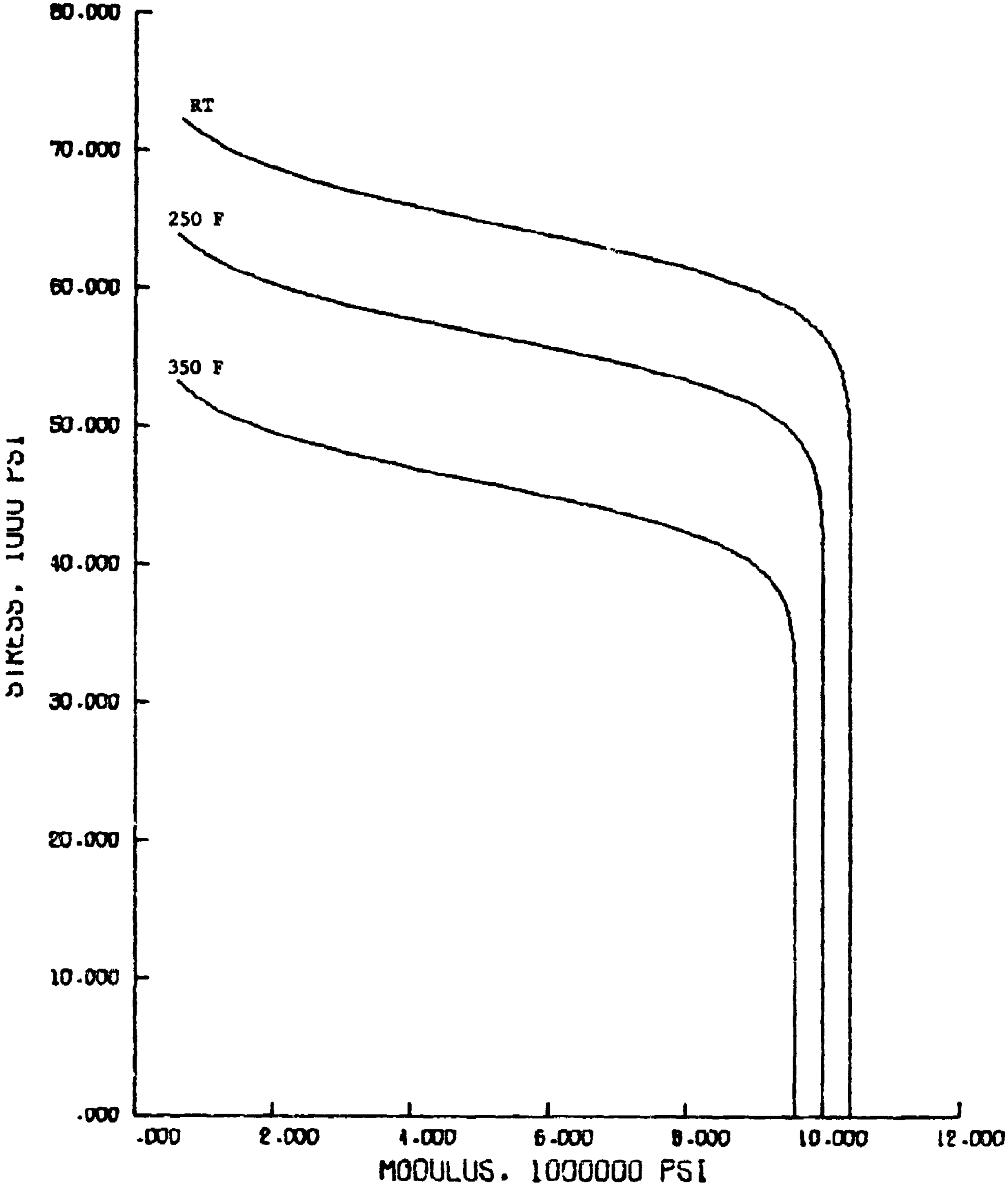

FIGURE 80. TYPICAL COMPRESSIVE TRANSVERSE TANGENT-MODULUS CURVES AT TEMPERATURE FOR 7175-T76511 ALUMINUM ALLOY EXTRUSIONS

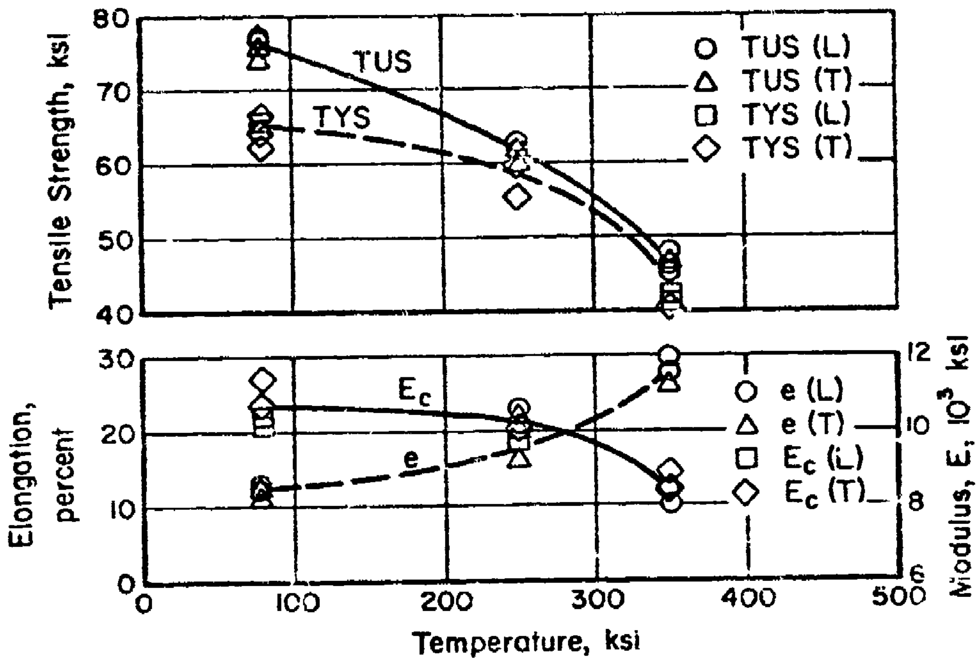

FIGURE 81. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 7175-T76511 ALUMINUM ALLOY EXTRUSIONS

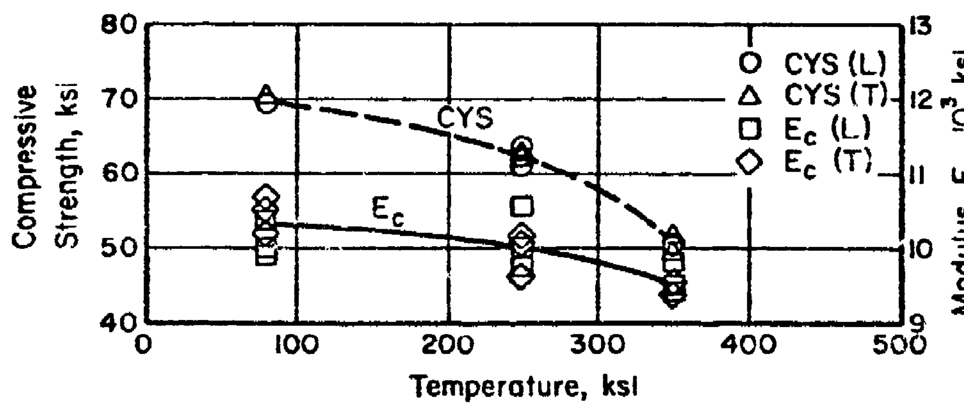

FIGURE 82. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 7175-T76511 ALUMINUM ALLOY EXTRUSIONS

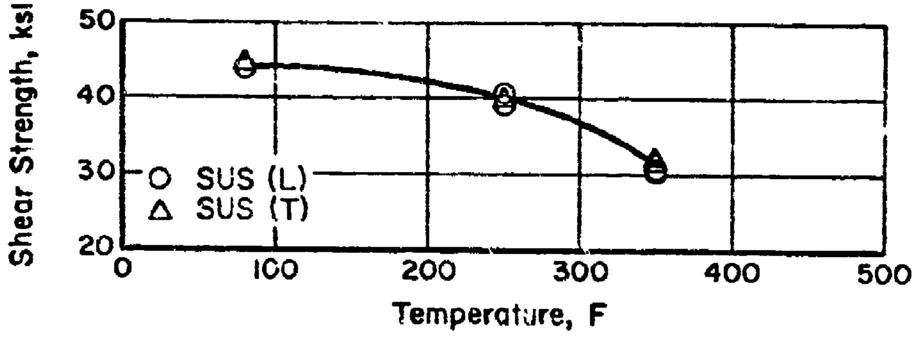

FIGURE 83. EFFECT OF TEMPERATURE ON THE SHEAR PROPERTIES OF 7175-T76511 ALUMINUM ALLOY EXTRUSIONS

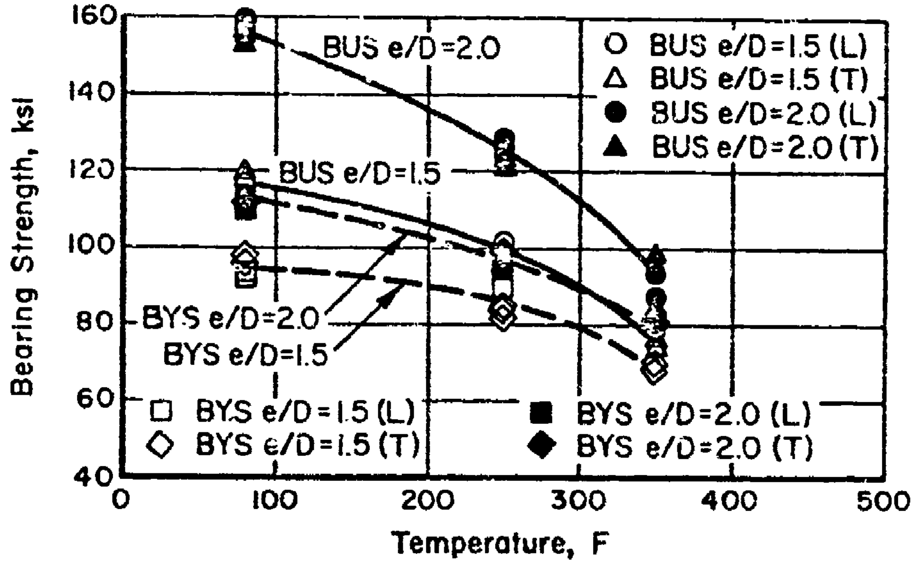

FIGURE 84. EFFECT OF TEMPERATURE ON THE BEARING PROPERTIES OF 7175-T76511 ALUMINUM ALLOY EXTRUSIONS

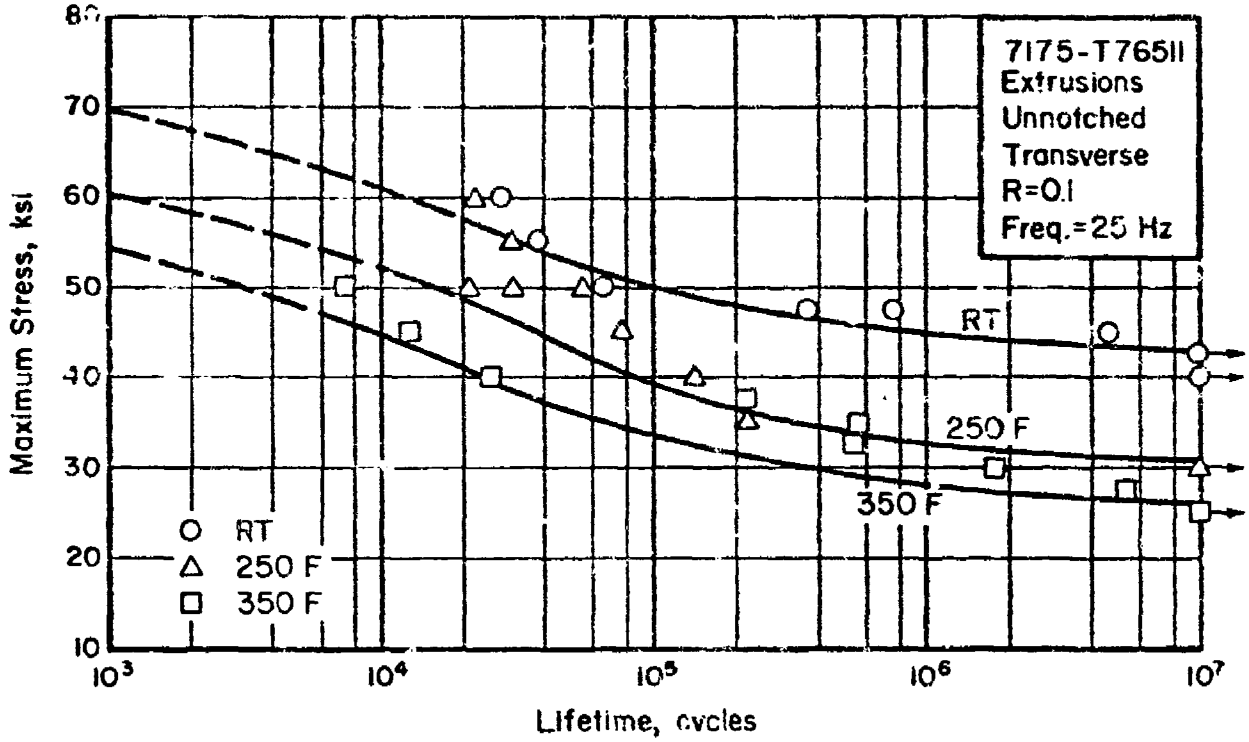

FIGURE 85. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED, TRANSVERSE 7175-T76511 ALUMINUM ALLOY EXTRUSIONS

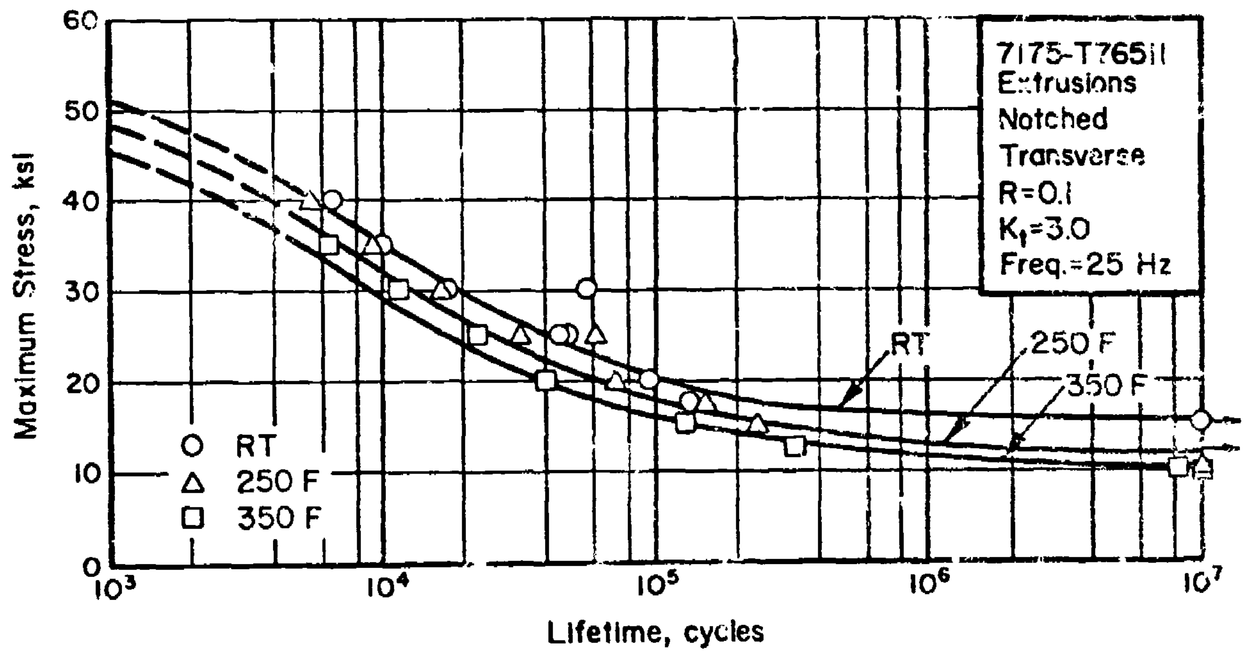

FIGURE 86. AXIAL LOAD FATIGUE BEHAVIOR OF TRANSVERSE, NOTCHED (K_t = 3.0) 7175-T76511 ALUMINUM ALLOY EXTRUSIONS

4330M Steel Forgings

Material Description

A limited evaluation of 4330M forgings, related to a service problem, was performed as a modification to the contract. The material was a forging used in airframe structure related to the horizontal stabilizer.

Processing and Heat-Treating

The forgings were heat-treated (quenched and tempered) to the 220-240 ksi tensile strength level. As directed, only limited room temperature tests were performed.

Test Results

Tension. Results of longitudinal and transverse tests are given in Table LX. Typical tensile stress-strain curves are presented in Figure 87.

Compression. Results of longitudinal and transverse tests are given in Table LXI. Typical compressive stress-strain and tangent-modulus curves are shown in Figures 88 and 89.

Shear. Results of pin shear type tests for longitudinal and transverse specimens are given in Table LXII.

Impact. Results of Charpy impact tests for longitudinal and transverse specimens are given in Table LXIII.

Fracture Toughness. Results of compact tension type tests for transverse - short transverse specimens are given in Table LXIV. Per ASTM E399 the candidate K_Q values shown are valid K_{Ic} values.

Fatigue. Results of axial-load fatigue tests for unnotched and notched longitudinal specimens are given in Table LXV. S-N curves are presented in Figure 90.

TABLE LX. RESULTS OF TENSILE TESTS ON 4330 M STEEL FORGINGS AT ROOM TEMPERATURE

Specimen Number	Tensile Ultimate Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 1 Inch, percent	Reduction in Area, percent	Tensile Modulus, 10^3 ksi
		Longitudinal			
1L-1	243.6	202.9	12.0	51.6	28.5
1L-2	244.5	203.5	12.0	46.8	29.0
1L-3	245.2	205.0	13.0	51.7	29.3
Average	244.4	203.8	12.3	50.0	28.9
		Transverse			
1T-1	243.4	202.7	11.5	47.6	29.1
1T-2	242.4	201.7	12.5	49.4	28.7
1T-3	241.4	202.9	12.0	48.2	29.3
Average	242.4	202.4	12.0	48.4	29.0

TABLE LXI. RESULTS OF COMPRESSION TESTS ON 4330 M STEEL FORGINGS AT ROOM TEMPERATURE

Specimen Number	0.2 Percent Offset Yield Strength, ksi	Compression Modulus, 10^3 ksi
	Longitudinal	
2L-1	223.2	29.1
2L-2	220.7	29.7
2L-3	220.3	29.1
Average	221.4	29.3
	Transverse	
2T-1	221.2	29.7
2T-2	221.9	29.2
2T-3	222.6	29.8
Average	221.9	29.6

TABLE LXII. RESULTS OF PIN SHEAR TESTS ON 4330 M STEEL FORGINGS AT ROOM TEMPERATURE

Specimen Number	Shear Ultimate Strength, ksi
Longitudinal	
4L-1	160.0
4L-2	159.2
4L-3	159.6
Average	159.6
Transverse	
4T-1	157.0
4T-2	157.2
4T-3	157.1
Average	157.1

TABLE LXIII. RESULTS OF CHARPY IMPACT TESTS ON 4330 M STEEL FORGINGS AT ROOM TEMPERATURE

Specimen Number	Energy, ft. lbs.
Longitudinal	
10L-1	15.0
10L-2	15.0
10L-3	16.0
Average	15.3
Transverse	
10T-1	14.0
10T-2	15.0
10T-3	13.5
Average	14.2

TABLE LXIV. RESULTS OF COMPACT TENSION TYPE FRACTURE TOUGHNESS TESTS ON 4330 M STEEL FORGINGS AT ROOM TEMPERATURE

Specimen Number	W, inches	B, inches	a, inches	P_Q, lbs.	P_{max},	f(a/w)	K_Q
			T - ST Direction				
6-1	2.0	1.0	.976	11480	11640	9.2325	74.9
6-2	2.0	1.0	.994	11040	11220	9.4788	75.2
6-3	2.0	1.0	.991	11800	12000	9.4369	78.7
						Average	76.3

TABLE LXV. AXIAL LOAD FATIGUE TEST RESULTS FOR 4330 M STEEL FORGINGS AT ROOM TEMPERATURE (LONGITUDINAL, R = 0.1)

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
	Unnotched	
5-6	220	19,550
5-3	210	17,710
5-4	200	66,200
5-1	190	216,870
5-9	190	462,430
5-2	180	2,400,000
5-5	170	13,000,000[a]
	Notched, K_t = 3.0	
5-11	180	1,500
5-12	160	1,920
5-20	130	5,430
5-13	100	15,700
5-15	90	24,340
5-19	80	62,690
5-16	70	59,910
5-18	70	75,530
5-17	65	10,000,000[a]
5-14	60	17,000,000[a]

(a) Did not fail.

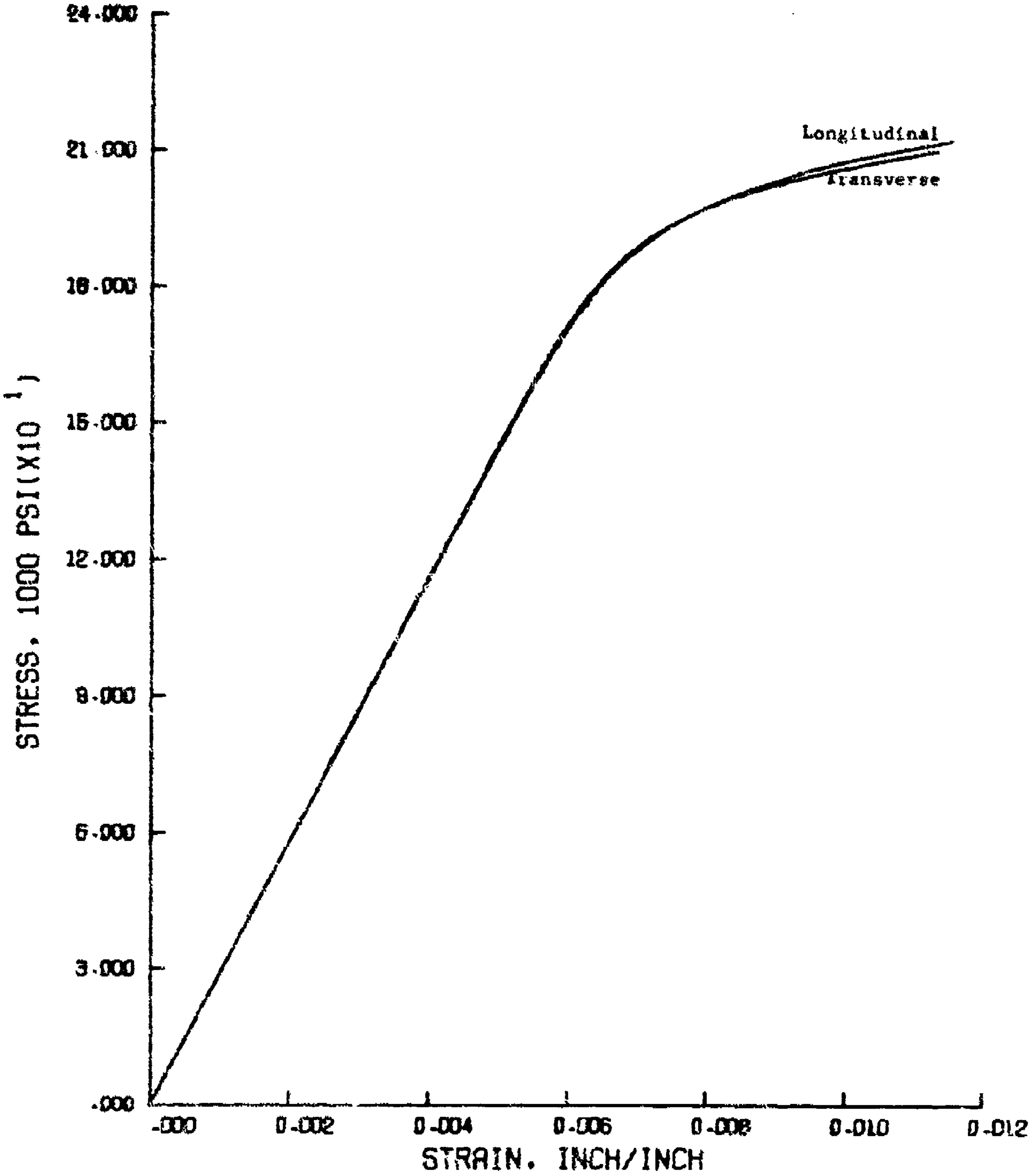

FIGURE 87. TYPICAL TENSILE STRESS-STRAIN CURVES FOR 4330 M STEEL FORGINGS AT ROOM TEMPERATURE

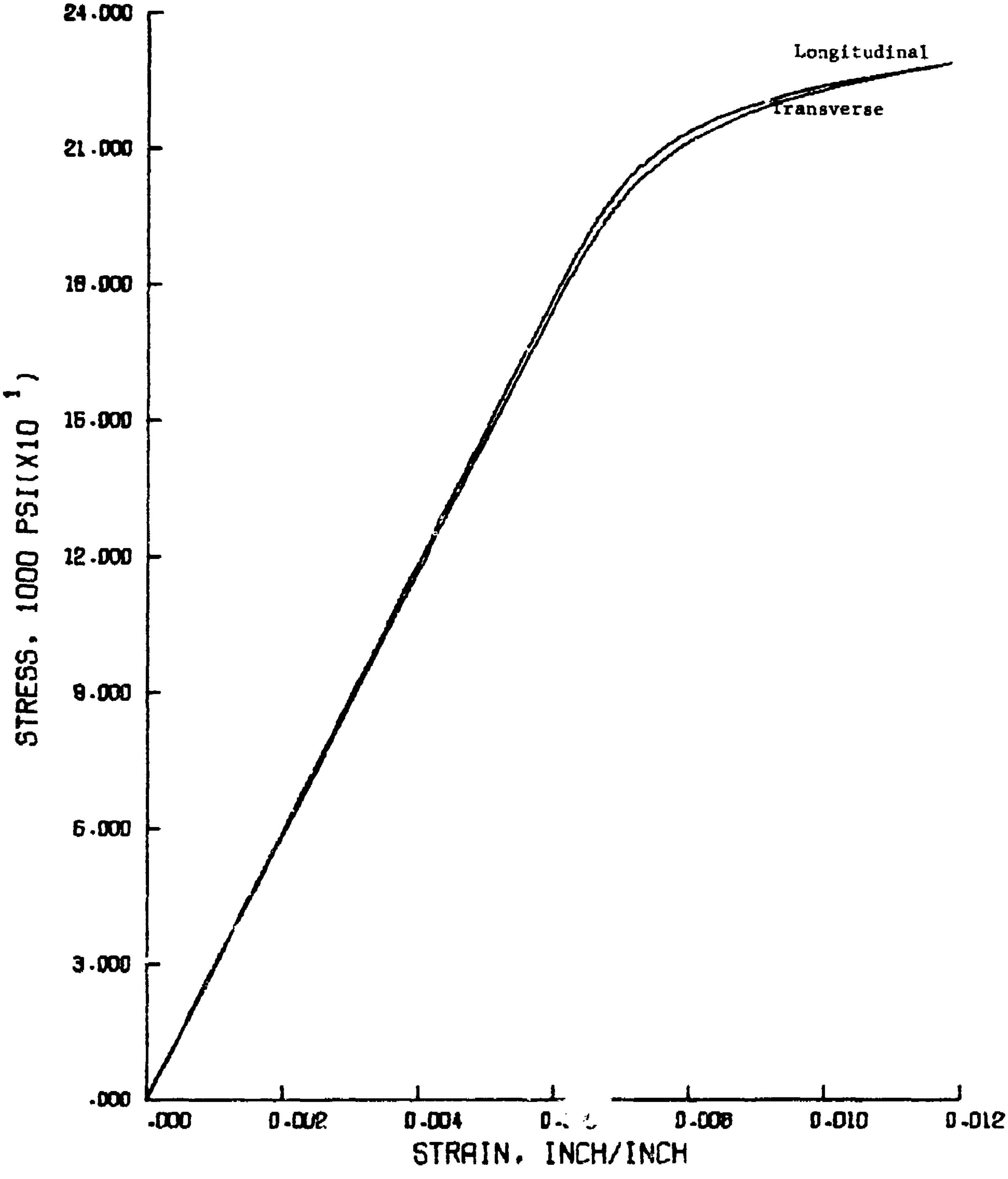

FIGURE 88. TYPICAL COMPRESSIVE STRESS-STRAIN CURVES FOR 4330 M STEEL FORGINGS AT ROOM TEMPERATURE

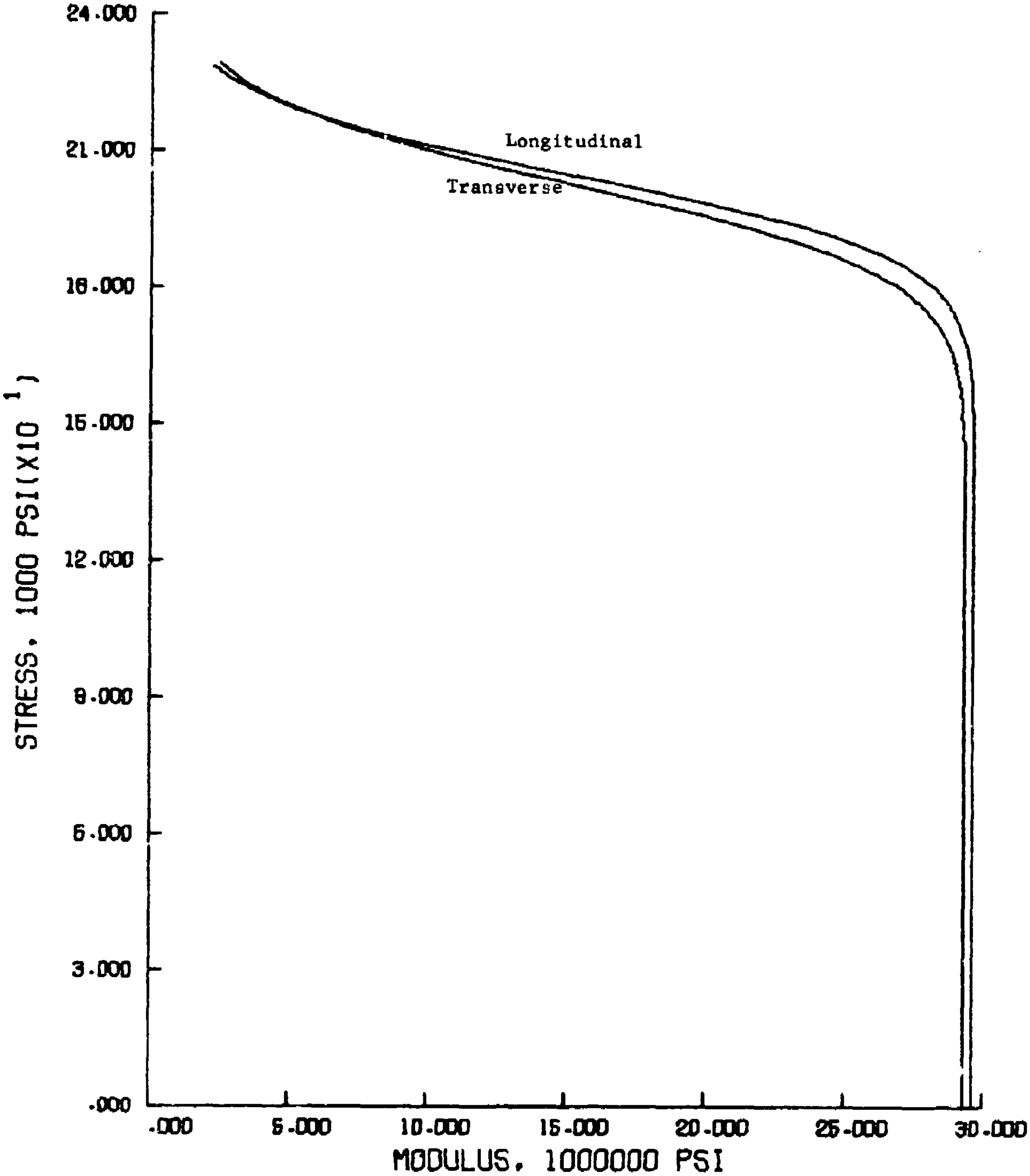

FIGURE 89. TYPICAL COMPRESSIVE TANGENT-MODULUS CURVES FOR 4330 M STEEL FORGINGS AT ROOM TEMPERATURE

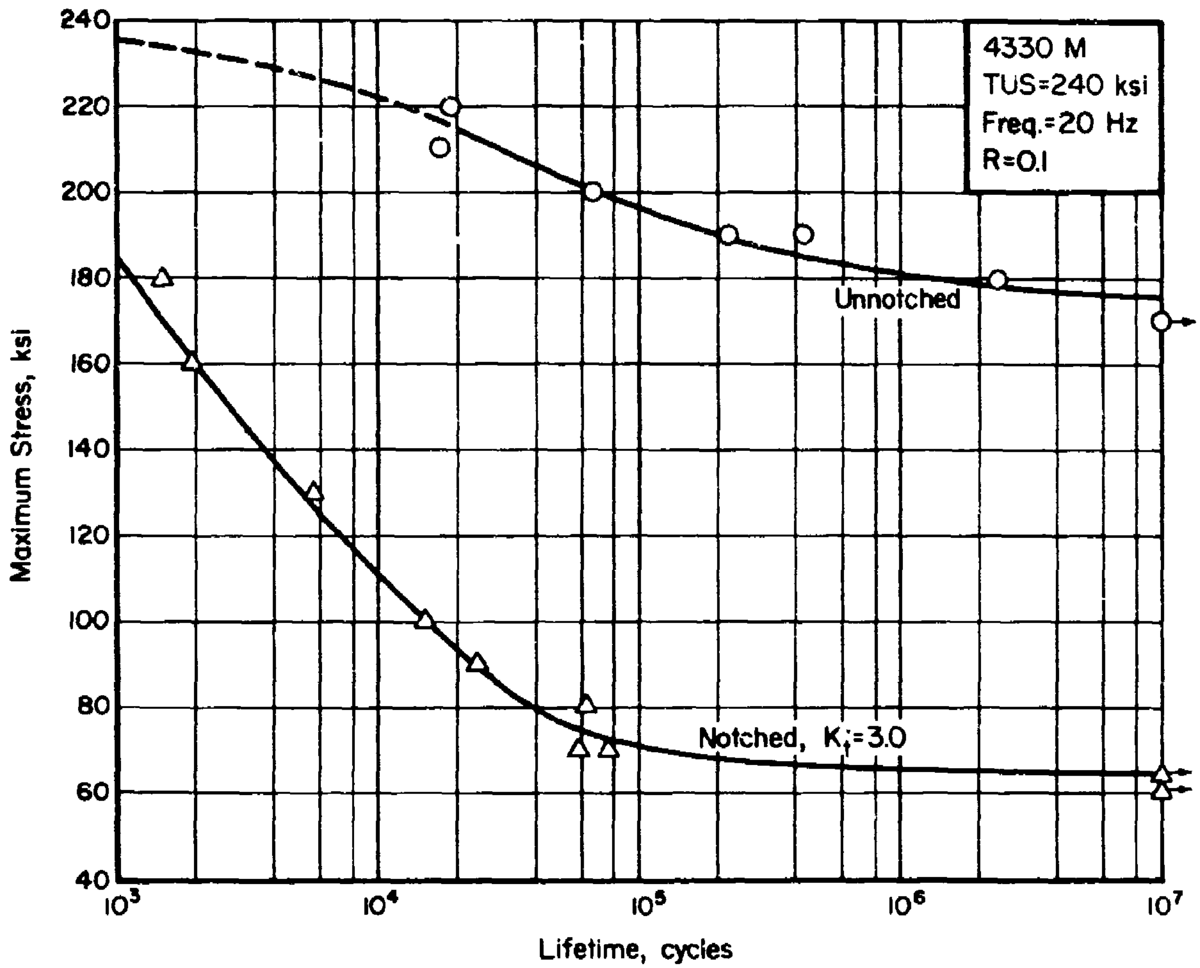

FIGURE 90. AXIAL-LOAD-FATIGUE BEHAVIOR OF 4330M AT ROOM TEMPERATURE

SECTION II

DISCUSSION OF PROGRAM RESULTS

The general tendency in an evaluation program of this type is to compare the materials property information obtained with similar data for materials already in use. Whether such a comparison should be the deciding factor for interest in a newer alloy is open to question. Many criteria, such as forming characteristics, oxidation resistance, weldability, etc., can be of particular importance in a particular application so that strength properties may become secondary. However, since first comparisons are usually made on the basis of mechanical strength (tensile ultimate and tensile yield), the materials evaluated on this program are compared to each other and similar alloys. Figures 91 and 92 are effect-of-temperature curves concerned with these properties.

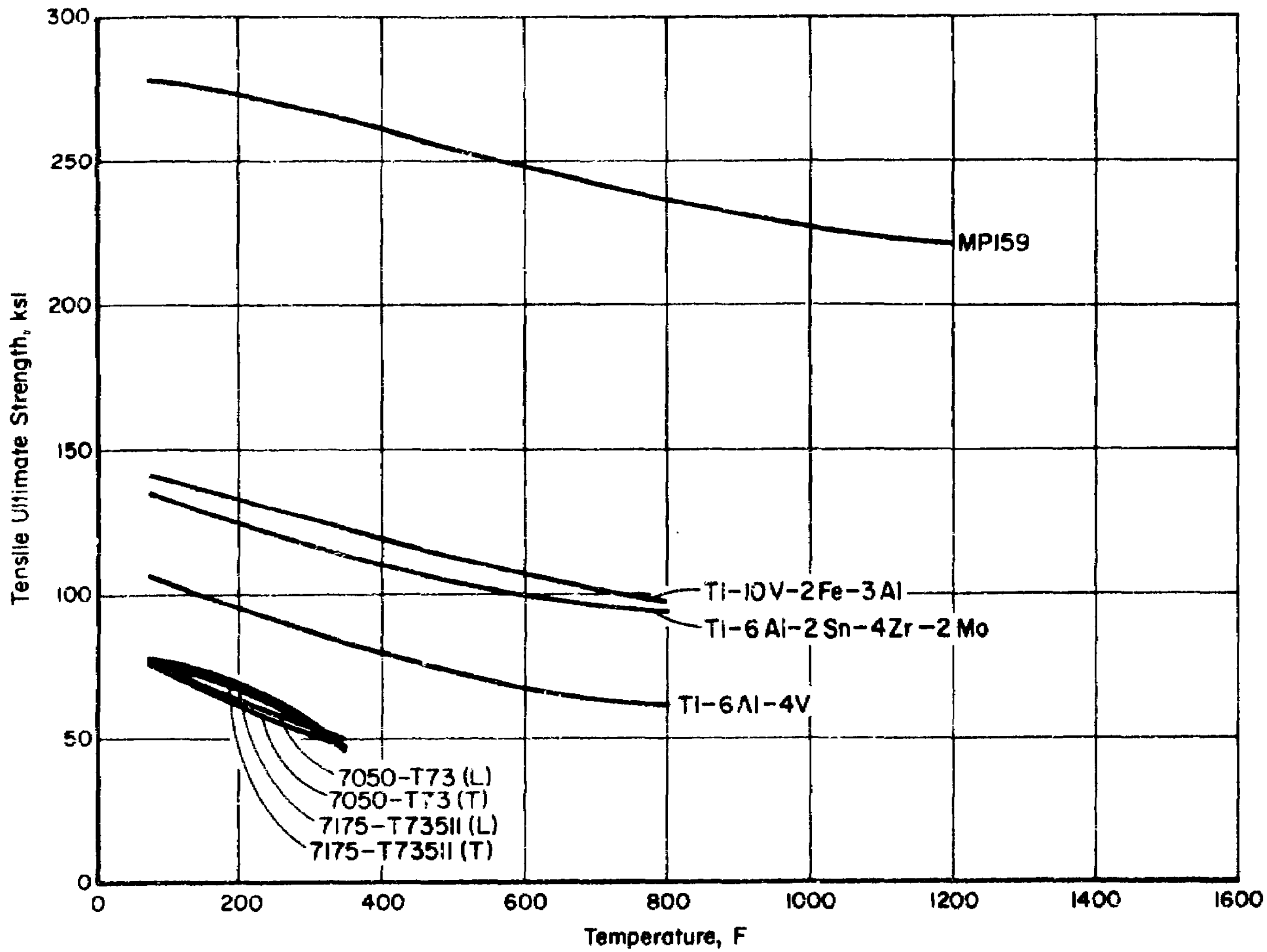

FIGURE 91. TENSILE ULTIMATE STRENGTH AS A FUNCTION OF TEMPERATURE

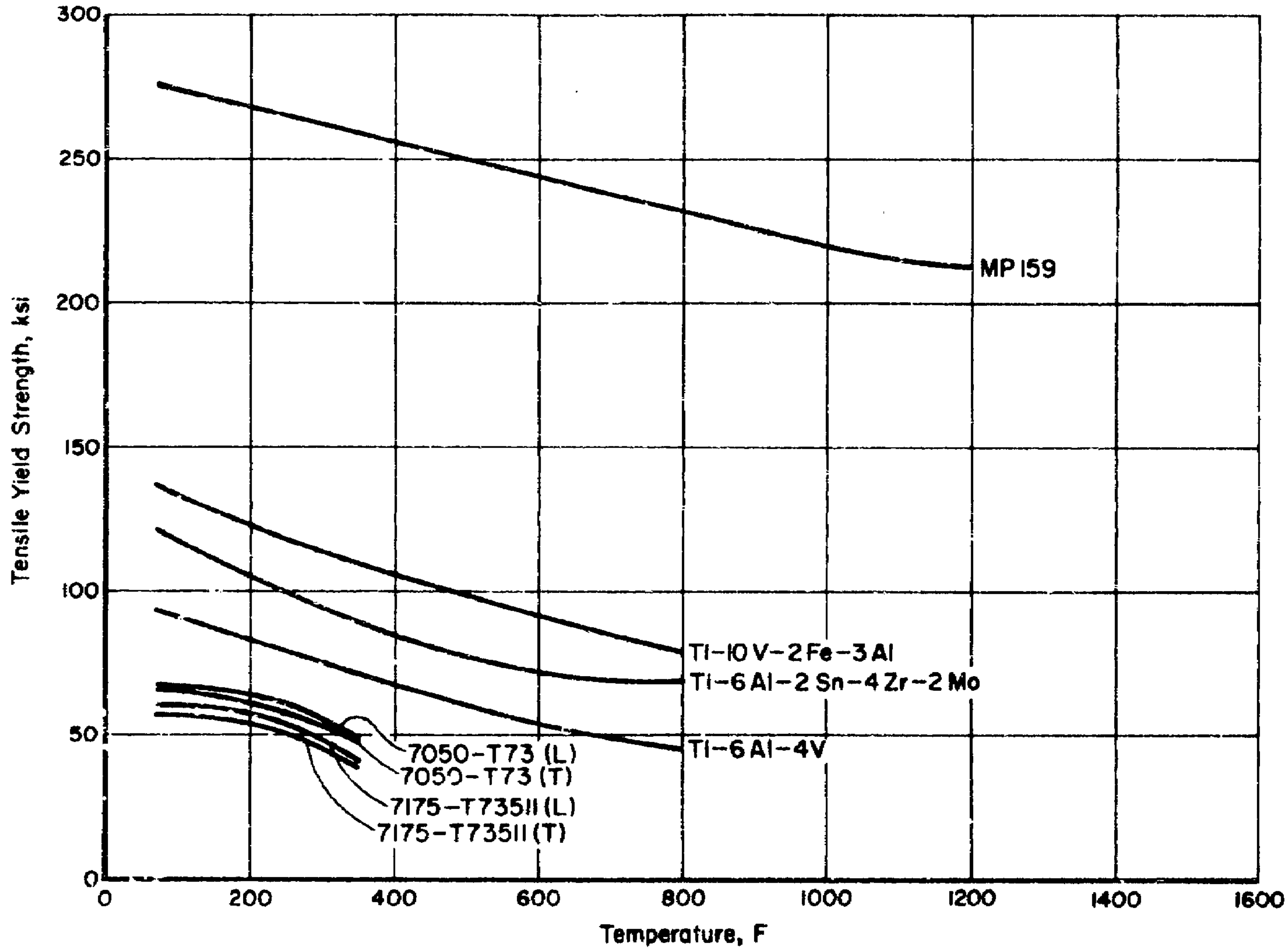

FIGURE 92. TENSILE YIELD STRENGTH AS A FUNCTION OF TEMPERATURE

SECTION III

CONCLUSIONS

The objective of this program was the generation of useful engineering data for newly developed materials. During the contract term, the following materials were evaluated:

1) MP 159 Multiphase Bar
2) Ti-6Al-2Sn-4Zr-2Mo Castings
3) 7175-T73511 Extrusions
4) 7050-T73 Extrusions
5) Ti-6Al-4V PM Product
6) Ti-6Al-4V Superplastically Formed Product
7) Ti-10V-2Fe-3Al Round Bar
8) 7175-T76511 Extrusions
9) 4330 M Steel Forgings.

A data sheet was issued for each material. As a summary, each of the data sheets is reproduced in Appendix C.

APPENDIX A

EXPERIMENTAL PROCEDURE

Mechanical Properties

The various mechanical properties of interest for each of the materials are as follows:

(1) Tension

(a) Tensile ultimate strength, TUS

(b) Tensile yield strength, TYS

(c) Elongation, e_t

(d) Reduction in area, RA

(e) Modulus of elasticity, E_t.

(2) Compression

(a) Compressive yield strength, CYS

(b) Modulus of elasticity, E_c.

(3) Creep and stress-rupture

(a) Stress for 0.2 or 0.5 percent deformation in 100 hours and 1000 hours

(b) Stress for rupture in 100 hours and 1000 hours.

(4) Shear

(a) Shear ultimate strength, SUS.

(5) Axial fatigue*

(a) Unnotched, R = 0.1, lifetime: 10^3 through 10^7 cycles

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* "R" represents the algebraic ratio of the minimum stress to the maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(b) Notched (K_t = 3.0), R = 0.1, lifetime: 10^3 through 10^7 cycles.

(6) Fracture toughness, K_{Ic} or K_c.

(7) Stress corrosion

(a) 80 percent TYS for 1000 hours maximum, 3½ percent NaCl solution.

(8) Thermal expansion.

(9) Bend (no bend tests were conducted on this program).

(10) Impact

(a) Charpy V-notch.

(11) Density.

(12) Bearing

(a) Bearing ultimate strength, BUS

(b) Bearing yield strength, BYS.

Specimen Identification

A simple system of numbers and letters was used for specimen identification. Coding consisted of a number indicating the type of test and also indicating a comparable area on the sheet, plate, or forging. For certain test types, the number was followed by a letter signifying specimen orientation (L for longitudinal, T for transverse, ST for short transverse). The test types where the letter did not appear were creep, fatigue, and bend since, in these cases, only one specimen orientation was used. The next number in the coding specifies the location from which the specimen blank was taken from the original material configuration. Coding was as follows:

Assigned Number	Test Type
1	Tension
2	Compression
3	Creep and stress rupture
4	Shear
5	Fatigue

Assigned Number	Test Type
6	Fracture toughness
7	Stress corrosion
8	Thermal expansion
9	Bend
10	Impact
11	Density

As an example, a specimen numbered 2-T5 is a compression specimen, transverse orientation, cut from Location 5. Also, a specimen numbered 5-12 is a fatigue specimen cut from Location 12.

Test Description

Tension

Procedures used for tension testing are those recommended in ASTM methods E8-69 and E21-70. In general, six specimens (three longitudinal and three transverse) were tested at each temperature to determine ultimate tensile strength, 0.2 percent offset yield strength, elongation, and reduction in area. The modulus of elasticity was obtained from load-strain curves plotted by an autographic recorder during each test.

All tensile tests were carried out in Baldwin Universal testing machines. These machines are calibrated at frequent intervals in accordance with ASTM method E4-72 to assure loading accuracy within 0.2 percent. The machines are equipped with integral automatic strain pacers and autographic strain recorders.

Specimens tested at elevated temperatures were heated in standard wire-wound resistance-type furnaces. Each furnace was equipped with a Foxboro controller capable of maintaining the test temperature to within 5 F of the control temperature over a 2-inch gage length. Chromel-Alumel thermocouples attached to the specimen gage section were used to monitor temperatures. Each specimen was soaked at temperature at least 20 minutes before being tested.

An averaging-type linear differential transformer extensometer was used to measure strain. For elevated temperature testing, the extensometer was equipped with extensions to bring the transformer unit out of the furnace. The extensometer conformed to ASTM E83-67 Classification B1 having a sensitivity of 0.0001 inch/inch. The strain rate in the elastic region was maintained at 0.005 inch/inch/minute. After yielding occurred, the head speed was increased to 0.1 inch/inch/minute until fracture.

Compression

Procedures for conducting compression tests are outlined in ASTM method E9-70 along with temperature control provisions of E-21-70. All sheet and thin plate tests were carried out in Baldwin Universal testing machines using a North American type compression fixture as shown in Reference 2. Specimen heating was accomplished by a forced-air furnace for temperatures up to 1000 F. Specimen temperature was maintained by means of a Wheelco pyrometer. Three Chromel-Alumel thermocouples attached to the fixture were used to monitor temperatures to within 3 F of the test temperature. For higher temperatures, wire-wound furnaces were used with controls as described in the tensile test section.

The extensometer used for the compression tests was quite similar to that used in the tensile testing. The extension arms were fastened to the specimen at small notches spanning a 2-inch gage length. The output from the microformer was fed into a load-strain recorder to provide autographic load-strain curves. During testing the strain rate was adjusted to 0.005 inch/inch/minute.

For bar and forging material, cylindrical specimens similar to those described in ASTM E9-70 were used with appropriate temperature control and strain measurement as described above.

Six specimens (three longitudinal and three transverse) were tested at each temperature.

Shear

Single-shear sheet-type specimens were used for sheet and thin-plate material; for bar and forgings, a double-shear pin-type was used. A minimum of six specimens (three longitudinal and three transverse) were used to determine ultimate shear strength at each temperature.

Bearing

Bearing tests were conducted in accordance with ASTM E238. All tests were "clean pin" tests as described in this specification. In general, six longitudinal (three at $e/D = 1.5$, three at $e/D = 2.0$), and six transverse (three at $e/D = 1.5$, three at $e/D = 2.0$) specimens were tested at each temperature.

Creep and Stress Rupture

Standard dead-weight type creep testing frames were used for the creep and stress-rupture tests. These machines are calibrated to operate well within the accuracy requirements of ASTM method E139-70.

Specimens similar to those used for tension tests were used for the creep and stress-rupture studies. A platinum strip "slide rule" extensometer is attached for measuring creep strain and three Chromel-Alumel thermocouples are attached to the gage section for temperature measurements. Extensometer measurements were made visually through windows in the furnace by means of a filar micrometer microscope in which the smallest division equals 0.00005 inch.

The furnace was of conventional Chromel A wire-wound design with taps along the side to allow for correcting small temperature differences. Furnace temperature was maintained to within $\pm$ 2 F by Foxboro controllers in response to signals from the centrally located thermocouple. The temperature of a specimen under test was stabilized for at least ½ hour prior to loading.

For each temperature condition creep and stress-rupture data were obtained to 100 and 1000 hours using as many specimens as necessary to obtain precise information. The percent creep deformation obtained was dependent on the material under test. In most instances stress-time curves were defined for 0.2 and 0.5 percent elongation.

Stress Corrosion

Seven specimens of each alloy were tested for susceptibility to stress-corrosion cracking by alternate immersion in 3½ percent sodium chloride solution at room temperature.

Specimens were prepared for testing by degreasing with acetone. Where a surface film remained from heat treating, it was abraded off one side and the adjacent long edge of five of the specimens, and left intact on the other two.

Each specimen was placed in a four-point loading fixture and deflected to a stress corresponding to 80 percent of the tensile yield strength of the particular material. The specimen was electrically insulated from the fixture by means of glass or sapphire rods. Deflection for a given maximum fiber stress was calculated by the following expression:

$$y = \frac{\sigma(3\ell^2 - 4a^2)}{12dE}$$

where

y = deflection

σ = maximum fiber stress

ℓ = distance between outer load points

a - distance between outer and inner load points

d = specimen thickness

E = modulus of specimen material.

Each stressed specimen was suspended on an alternate immersion unit. This unit alternately immersed specimens in the 3.5 percent sodium chloride solution for ten minutes and held them above the solution to dry for 50 minutes. Tests were continued to the first sign of cracking or for 1000 hours, whichever occurred first.

Specimens were given frequent low-power microscopic examinations to detect cracks. At the first sign of cracking the specimen was removed. At the conclusion of the test, selected samples were sectioned and examined metallographically for any indication of cracking. Representative samples in which cracks were found were also given a metallographic examination to establish the type and extent of the cracks.

Thermal Expansion

Linear-thermal-expansion measurements were performed in a recording dilatometer with specimens protected by a vacuum of about 2×10^{-5} mm of mercury. In this apparatus a sheet-type specimen is supported between two graphite structures inside a tantalum-tube heater element. On heating, the differential movement of the two structures caused by specimen expansion results in the displacement of the core of a linear-variable differential transformer. The output of the transformer is recorded continuously as a function of specimen temperature. The entire assembly is enclosed in a vacuum chamber.

The furnace is controlled to heat at the desired rate, usually 5 F per minute. Errors associated with measurements in this apparatus are estimated not to exceed $\pm$ 2 percent. This is based on calibration with materials of known thermal-expansion characteristics.

Fatigue

Fatigue tests were conducted using MTS electrohydraulic-servocontrolled testing machines. The frequency of cycling of these machines is variable to beyond 2,000 cpm depending on specimen rigidity. These machines operate with closed-loop deflection, strain or load control. Under load control used in this program, cyclic loads were automatically maintained (regardless of the required amount of ram travel) by means of load-cell feedback signals. The calibration and alignment of each machine are checked periodically. In each case, the dynamic load-control accuracy is better than $\pm$ 3 percent of the test load.

For elevated temperature studies, an induction heating coil controlled by a Lepel Induction Heater was used. A thermocouple placed on the center of the specimen controlled temperature to $\pm$ 5 degrees.

After machining and heat treating (when required), the edges of all sheet and plate specimens were polished according to Battelle-Columbus' standard practice prior to testing. The unnotched specimens were held against a rotating drum covered with emery paper and polished using a kerosene lubricant.

APPENDIX B

SPECIMEN DRAWINGS

Specimen drawings are presented on the following pages. Figures 93 through 102 show the specimens used for all the materials except Ti-6Al-4V superplastically formed alloy. The thin sheet specimens shown in the other figures were used, where applicable, for this material.

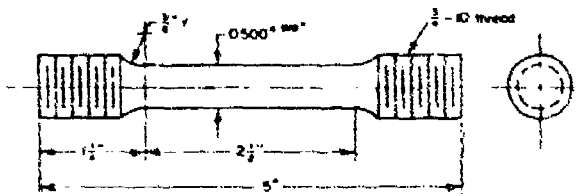


FIGURE 93. ROUND TENSILE SPECIMEN

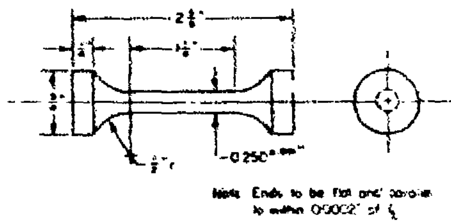
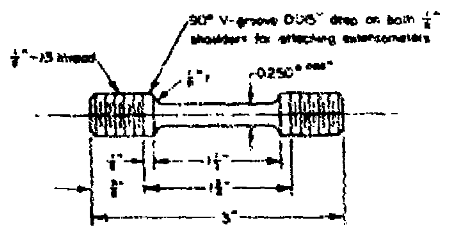


FIGURE 94. ROUND COMPRESSION SPECIMEN



A-1363

FIGURE 95. ROUND CREEP – AND STRESS-RUPTURE SPECIMEN

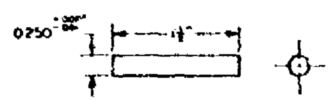


FIGURE 96. PIN SHEAR SPECIMEN

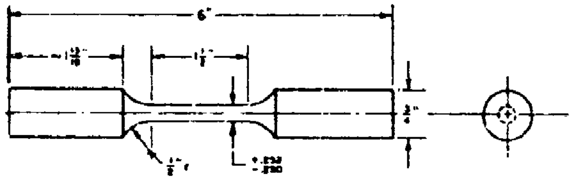


FIGURE 97. UNNOTCHED ROUND FATIGUE SPECIMEN

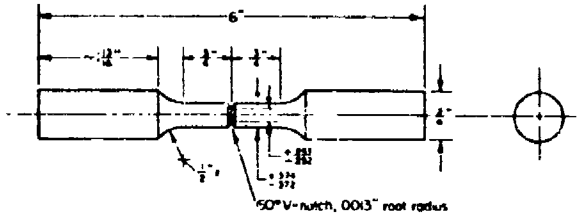


FIGURE 98. NOTCHED ROUND FATIGUE SPECIMEN

A-1226

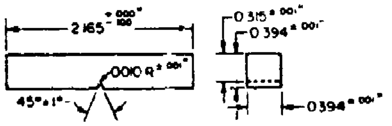


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FIGURE 99. NOTCHED IMPACT SPECIMEN

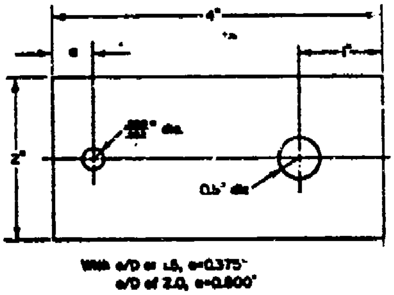

FIGURE 100. BEARING SPECIMEN

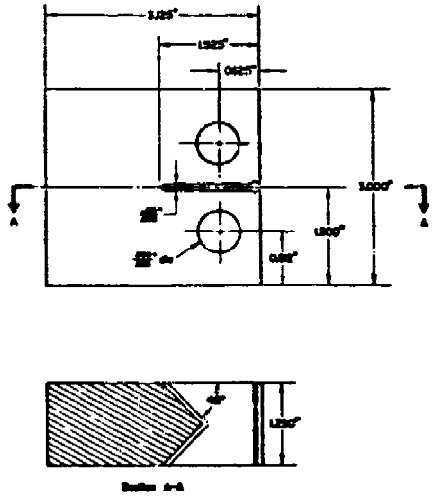

FIGURE 101. FRACTURE TOUGHNESS SPECIMEN

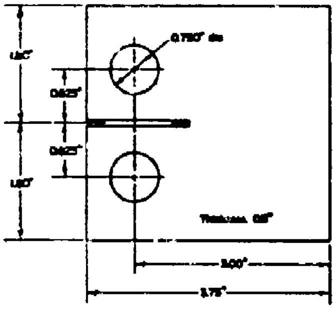

FIGURE 102. CRACK-GROWTH SPECIMEN

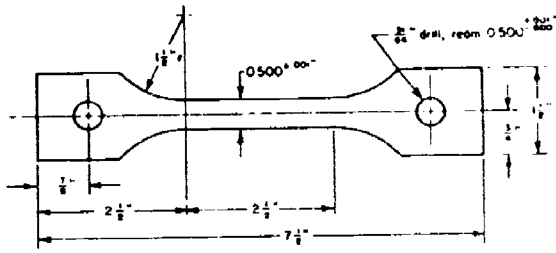

FIGURE 103. SHEET AND THIN-PLATE TENSILE SPECIMEN

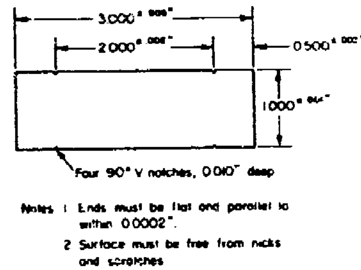

FIGURE 104. SHEET COMPRESSION SPECIMEN

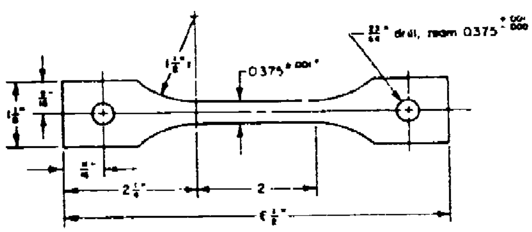

FIGURE 105. SHEET CREEP – AND STRESS-RUPTURE SPECIMEN

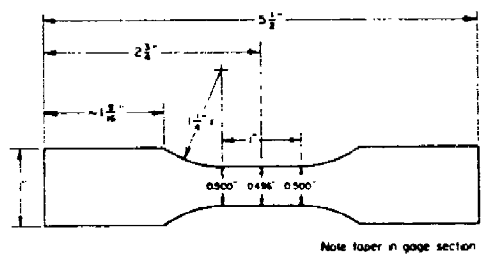

FIGURE 106. UNNOTCHED SHEET FATIGUE SPECIMEN

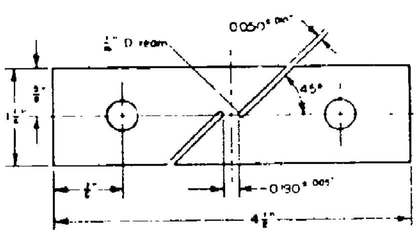

FIGURE 107. SHEET SHEAR TEST SPECIMEN

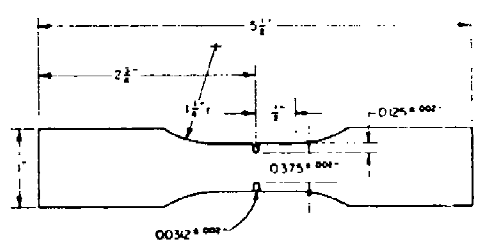

FIGURE 108. NOTCHED SHEET FATIGUE SPECIMEN

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APPENDIX C

DATA SHEETS

MP159 Multiphase Alloy

Material Description

MP159 Alloy is a recent addition to the Multiphase family of alloys developed by the Latrobe Steel Company. It possesses a unique combination of ultra high strength, ductility, and corrosion resistance. Through work strengthening and aging, the alloy exhibits tensile ultimate strength levels in excess of 265 ksi while maintaining reduction of area values greater than 30%. Excellent strength and ductility are also evident at elevated temperatures up to 1200 F. This alloy displays excellent resistance to crevice and stress corrosion in various hostile environments. Typical uses are fasteners and jet engine components.

The material used for this evaluation was .766-inch-diameter round bar from Latrobe Heat No. C52377. The material had the following composition:

Chemical Composition	Percent
Carbon	.014
Silicon	.01
Manganese	.01
Sulfur	.004
Phosphorus	.004
Iron	8.77
Chromium	18.95
Columbium	.64
Molybdenum	7.09
Cobalt	34.78
Titanium	2.99
Aluminum	.22
Nickel	Balance

Processing and Heat Treating

The material was received in the cold drawn-as drawn condition (48% work strengthed). After machining, the specimens received a 1225 F, 4 hour, air cool aging treatment.

MP159 Alloy Data[(a)]

Condition: Work Strengthened and Aged

Thickness: .766-Inch-Diameter Round Bar

Properties	Temperature, F RT	800	1200
Tension			
TUS (longitudinal), ksi	279.5	238.0	222.5
TYS (longitudinal), ksi	276.0	232.3	212.3
e (longitudinal), percent in 2 in.	6.3	5.8	5.0
RA (longitudinal), percent	27.7	29.0	15.7
E (longitudinal), 10^3 ksi	33.3	30.2	26.3
Compression			
CYS (longitudinal), ksi	283.5	233.9	215.1
E_c (longitudinal), 10^3 ksi	35.1	30.3	29.0
Shear[(b)]			
SUS (longitudinal), ksi	187.2	166.0	126.3
Impact			
V-notch Charpy, ft. lbs.	42.1[(d)]	U[(c)]	U
Axial Fatigue (longitudinal)			
Unnotched, R = 0.1			
10^3 cycles, ksi	270	235	218
10^5 cycles, ksi	212	212	200
10^7 cycles, ksi	118	118	140
Notched, K_t = 3.0, R = 0.1			
10^3 cycles, ksi	160	135	105
10^5 cycles, ksi	70	70	70
10^7 cycles, ksi	30	50	60

(Continued)

Properties	Temperature, F RT	800	1200
Creep (transverse)			
0.2% plastic deformation, 100 hr, ksi	NA[c]	180	94
0.2% plastic deformation, 1000 hr, ksi	NA	165	68
Stress Rupture (transverse)			
Rupture, 100 hr, ksi	NA	196.5	149
Rupture, 1000 hr, ksi	NA	196	110
Stress Corrosion[e]			
80% TYS, 1000 hr maximum	no cracks		
Coefficient of Thermal Expansion			
8.7×10^{-6} in./in./F (80 - 1200 F)			
Density			
0.302 lbs./in.^{3}			

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen; average of three tests in each direction.

(c) U, unavailable; NA, not applicable.

(d) Average of six tests.

(e) Room-temperature three-point bend test. Alternate immersion in 3-1/2% NaCl.

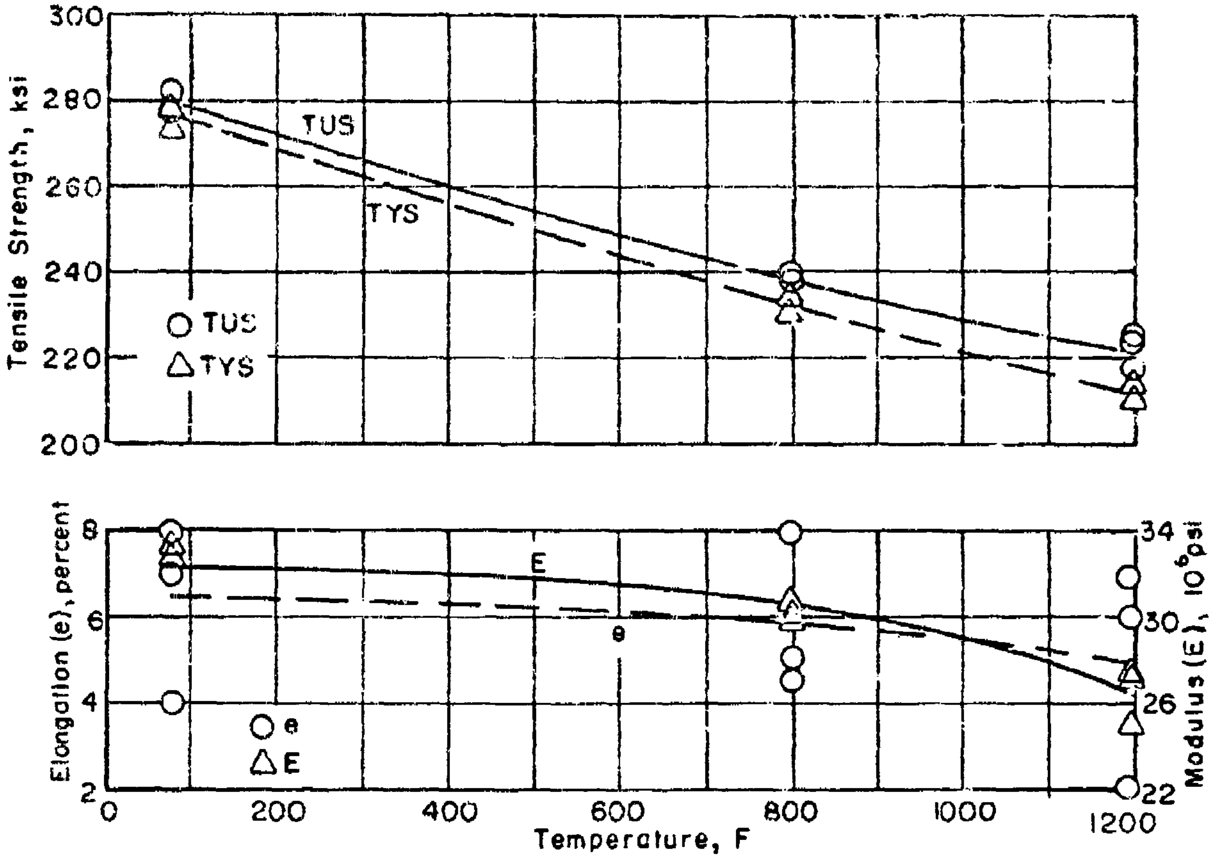

FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF WORK STRENGTHENED AND AGED MP159 ALLOY BAR

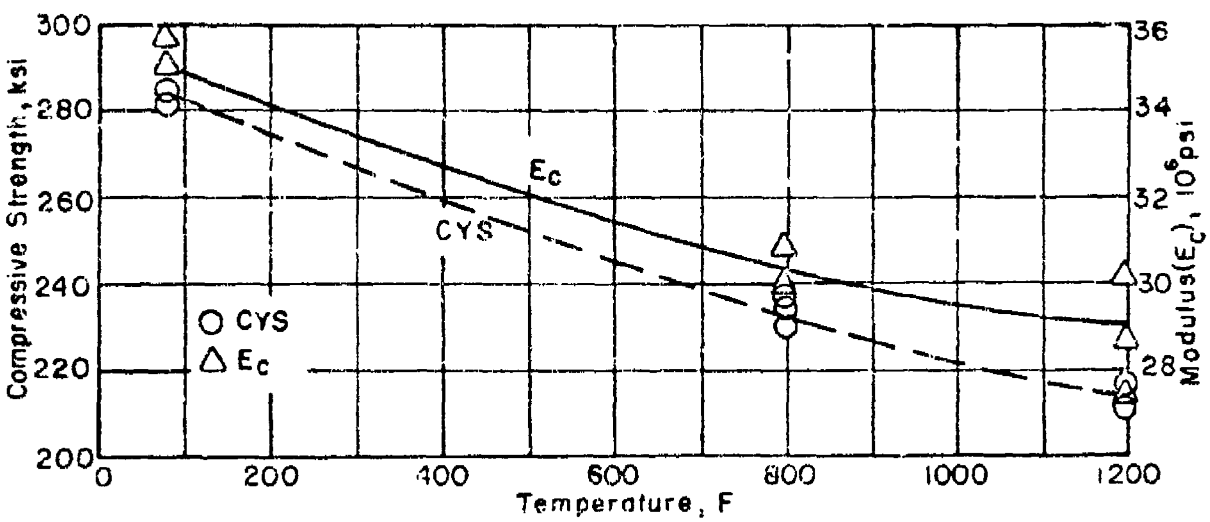

FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF WORK STRENGTHENED AND AGED MP159 ALLOY BAR

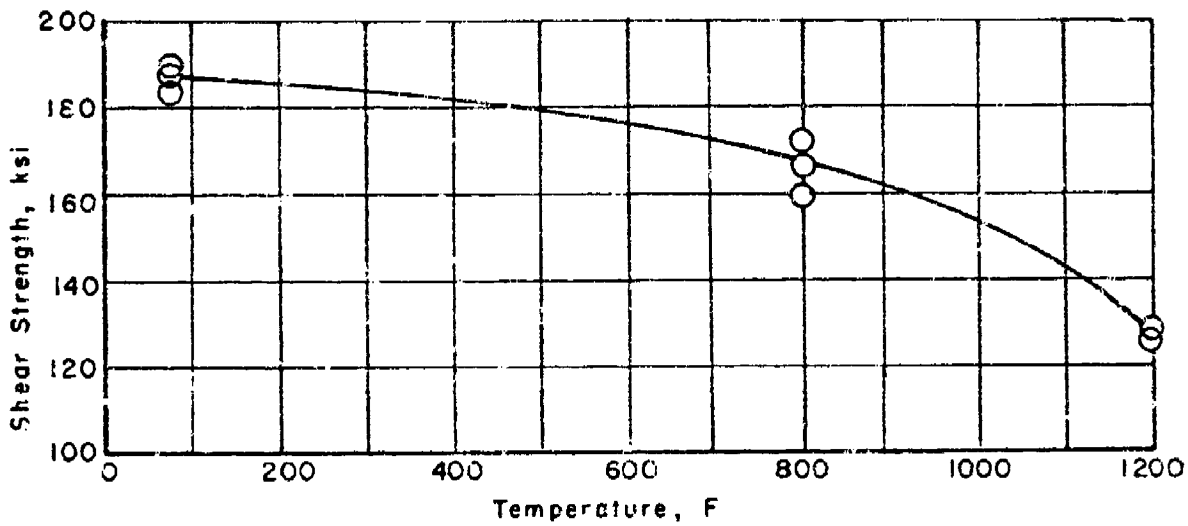

FIGURE 3. EFFECT OF TEMPERATURE ON THE SHEAR PROPERTIES OF WORK STRENGTHENED AND AGED MP159 ALLOY BAR

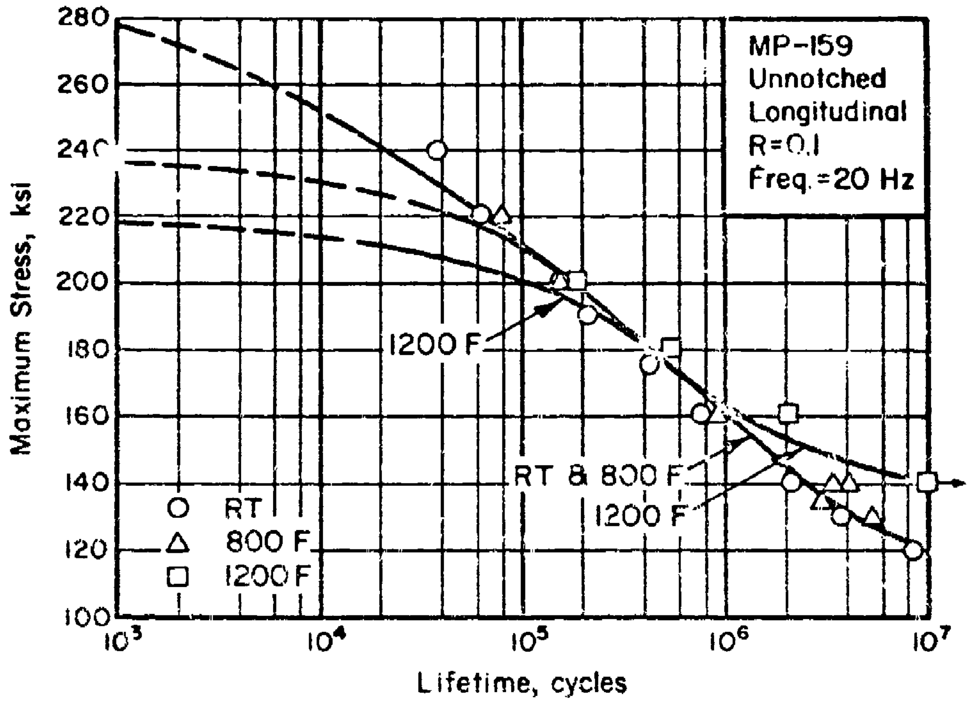

FIGURE 4. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED WORK STRENGTHENED AND AGED MP159 ALLOY BAR

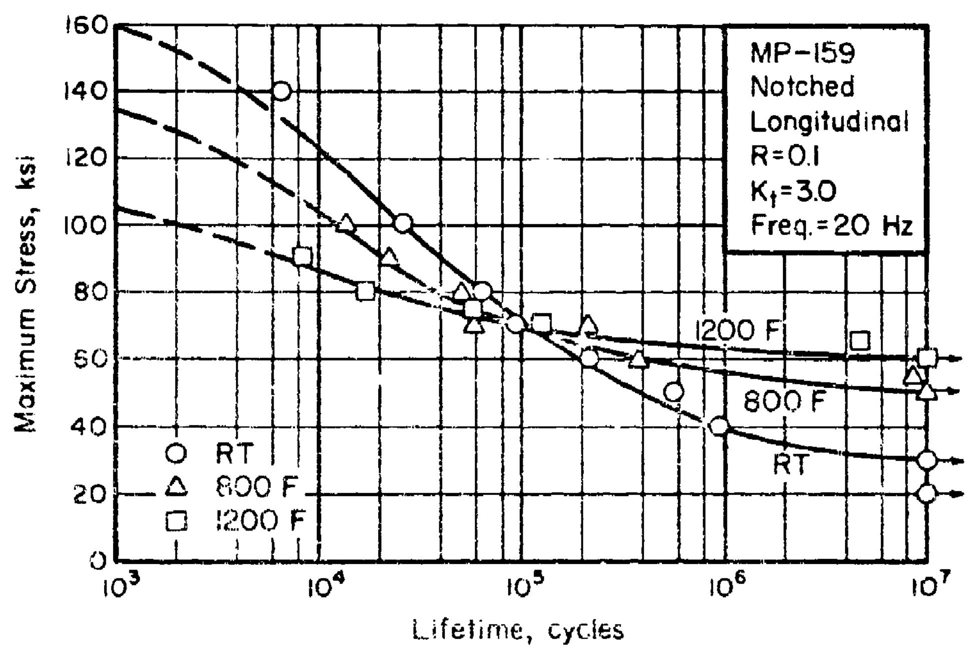

FIGURE 5. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) WORK STRENGTHENED AND AGED MP159 ALLOY BAR

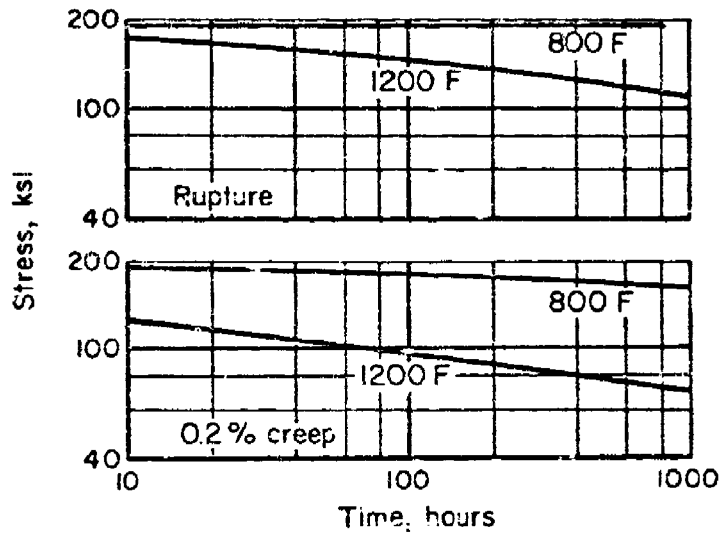

FIGURE 6. STRESS RUPTURE AND PLASTIC DEFORMATION CURVES FOR WORK STRENGTHENED AND AGED MP159 ALLOY BAR

Ti-6Al-2Sn-4Zr-2Mo Alloy

Material Description

This alloy is considered a super-alpha titanium alloy having an alpha-stabilized Ti-Al matrix solid solution strengthened by the additions of tin and zirconium. It has been primarily used in jet engine compressor parts and airframe skin components. It has good strength properties at elevated temperatures, and good creep properties and corrosion resistance.

Because of the current interest in titanium castings, the material chosen for this evaluation was 6 inch x 6½ inch cast wedges (tapered plates) manufactured by TiTech International and supplied by Rockwell International, Columbus Division. The composition was as follows:

Chemical Composition	Percent
C	.018
O	.168
H	.0047
N	.013
Al	6.02
Sn	2.04
Zr	3.80
Mo	2.07
Fe	.010
Si	.05

Processing and Heat Treating

The material was evaluated in the as-received as-cast condition.

Ti-6Al-2Sn-4Zr-2Mo Alloy Data[a]

Condition: As-Cast

Thickness: Tapered Wedge, 1 Inch to About ½ Inch

Properties	Temperature, F		
	RT	400	800
Tension			
TUS, ksi	135.2	110.3	94.7
TYS, ksi	121.0	85.9	69.4
e , percent in 1 inch	10.0	10.2	12.5
RA , percent	17.2	18.5	23.7
E , 10^3 ksi	17.3	15.9	14.9
Compression			
CYS, ksi	135.6	94.8	77.4
E_c , 10^3 ksi	17.1	16.1	14.5
Bearing			
e/D = 1.5			
BUS, ksi	221.6	186.2	159.6
BYS, ksi	195.5	156.1	131.1
e/D = 2.0			
BUS, ksi	296.7	226.0	199.9
BYS, ksi	251.9	185.1	154.6
Shear[b]			
SUS, ksi	95.3	73.1	62.5
Impact			
V-notch Charpy, ft.lbs.	14.9	U[c]	U
Fracture Toughness[d]			
K_{Ic}, ksi $\sqrt{in.}$	59.4	U	U

(Continued)

Properties	Temperature, F RT	700	800
Axial Fatigue			
Unnotched, R = 0.1			
10^3 cycles, ksi	125	87	86
10^5 cycles, ksi	62	56	56
10^7 cycles, ksi	28	22	22
Notched, K_t = 3.0, R = 0.1			
10^3 cycles, ksi	110	100	85
10^5 cycles, ksi	45	44	43
10^7 cycles, ksi	30	30	30
Creep			
0.2% plastic deformation, 100 hr, ksi	NA[c]	87	44
0.2% plastic deformation, 1000 hr, ksi	NA	79	35
Stress Rupture (transverse)			
Rupture, 100 hr, ksi	NA	92.5	35
Rupture, 1000 hr, ksi	NA	92	78
Stress Corrosion			
K_{Iscc}	(e)		
Coefficient of Thermal Expansion			
5.4×10^{-6} in./in./F (80 to 800 F)			
Density			
0.163 lb./in.^{3}			

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen; average of three tests.

(c) U, unavailable, NA, not applicable.

(d) Average of six tests.

(e) No appreciable crack growth could be obtained to measure K_{Iscc}.

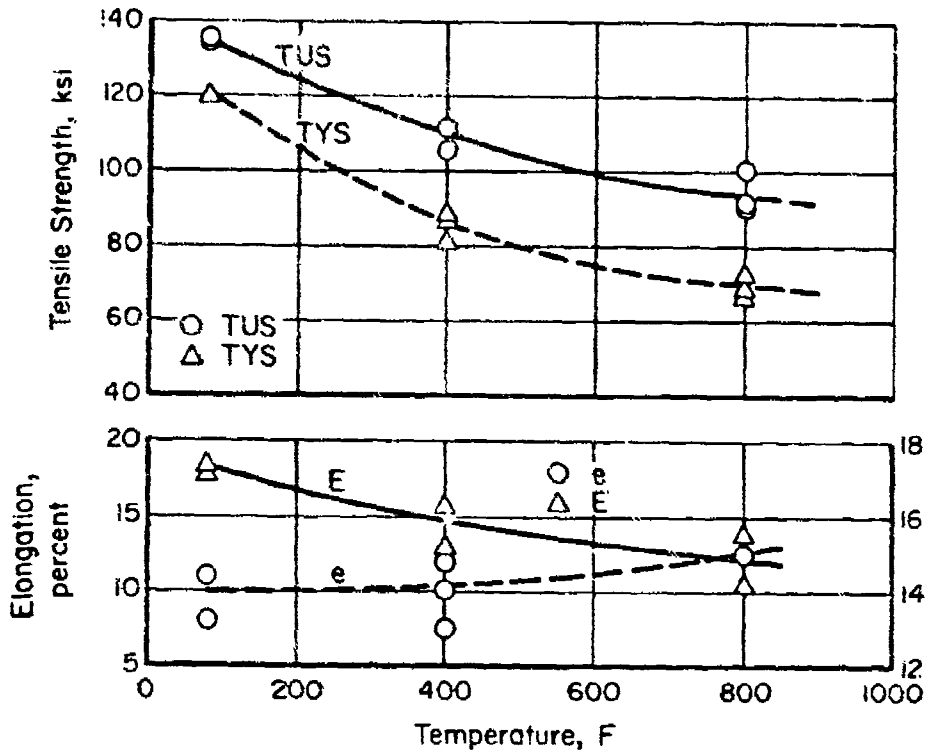

FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF Ti-6Al-2Sn-4Zr-2Mo ALLOY CASTINGS

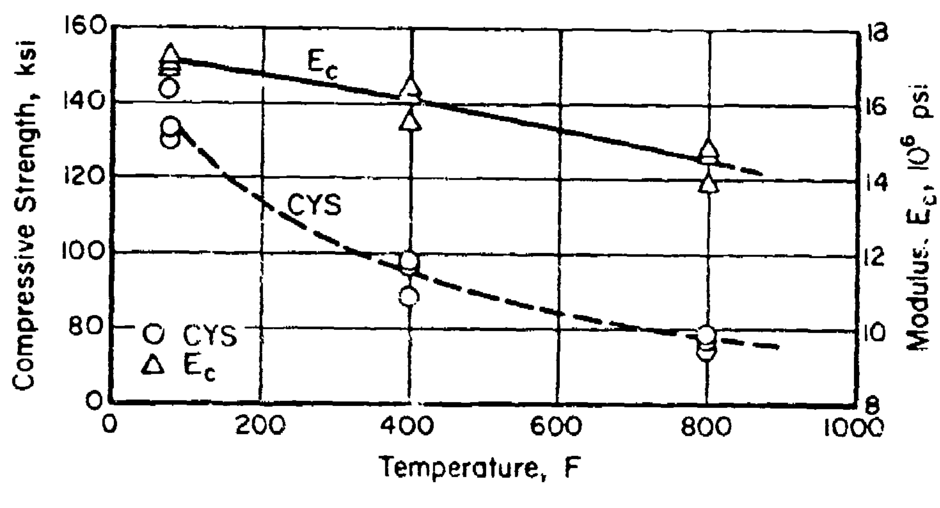

FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF Ti-6Al-2Sn-4Zr-2Mo ALLOY CASTING

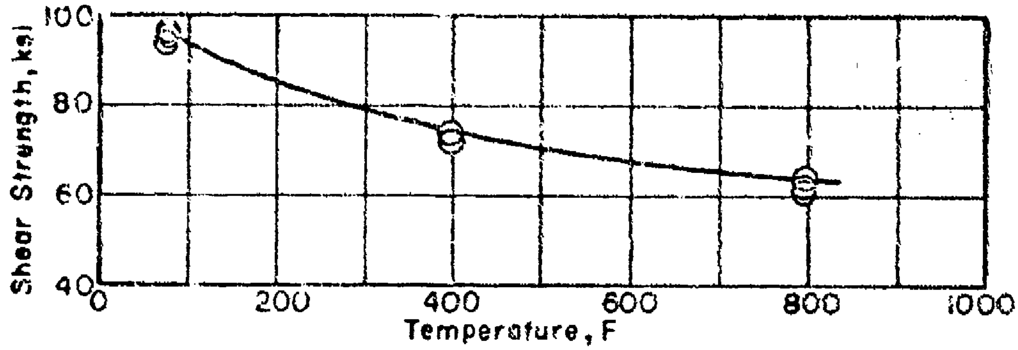

FIGURE 3. EFFECT OF TEMPERATURE ON THE SHEAR PROPERTIES OF Ti-6Al-2Sn-4Zr-2Mo ALLOY CASTING

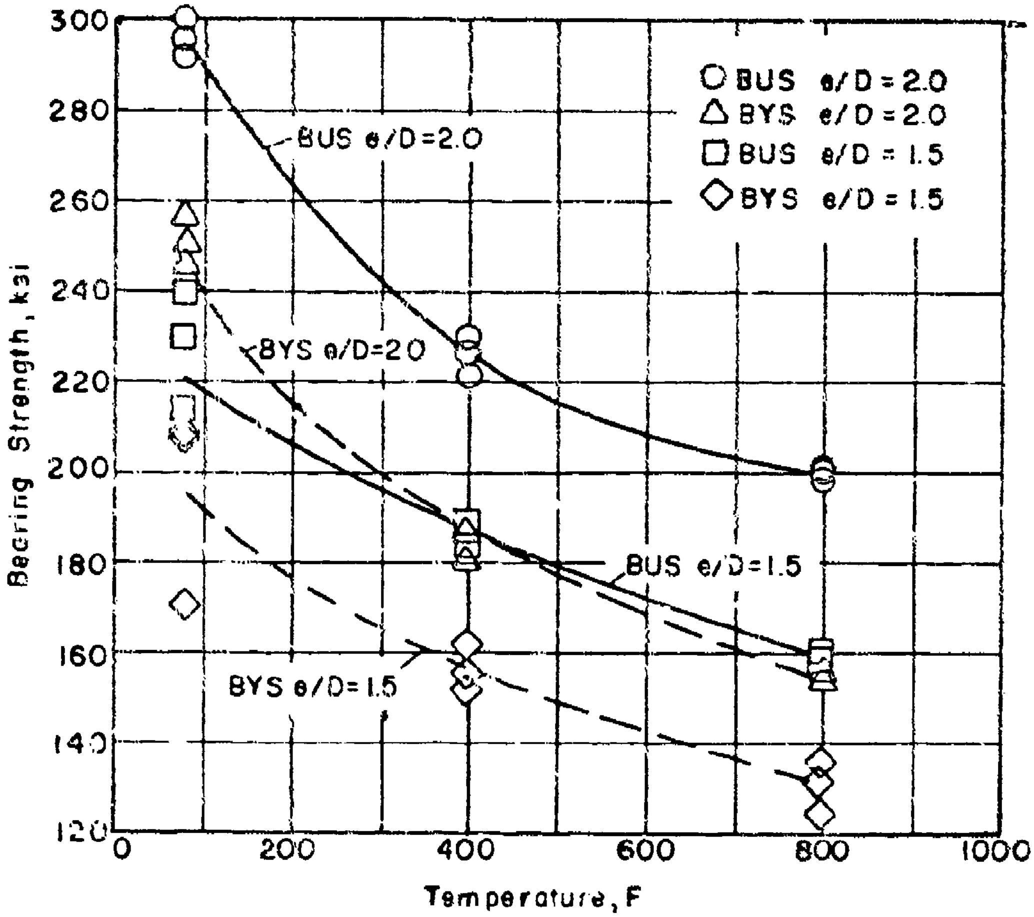

FIGURE 4. EFFECT OF TEMPERATURE ON THE BEARING PROPERTIES OF Ti-6Al-2Sn-4Zr-2Mo ALLOY CASTINGS

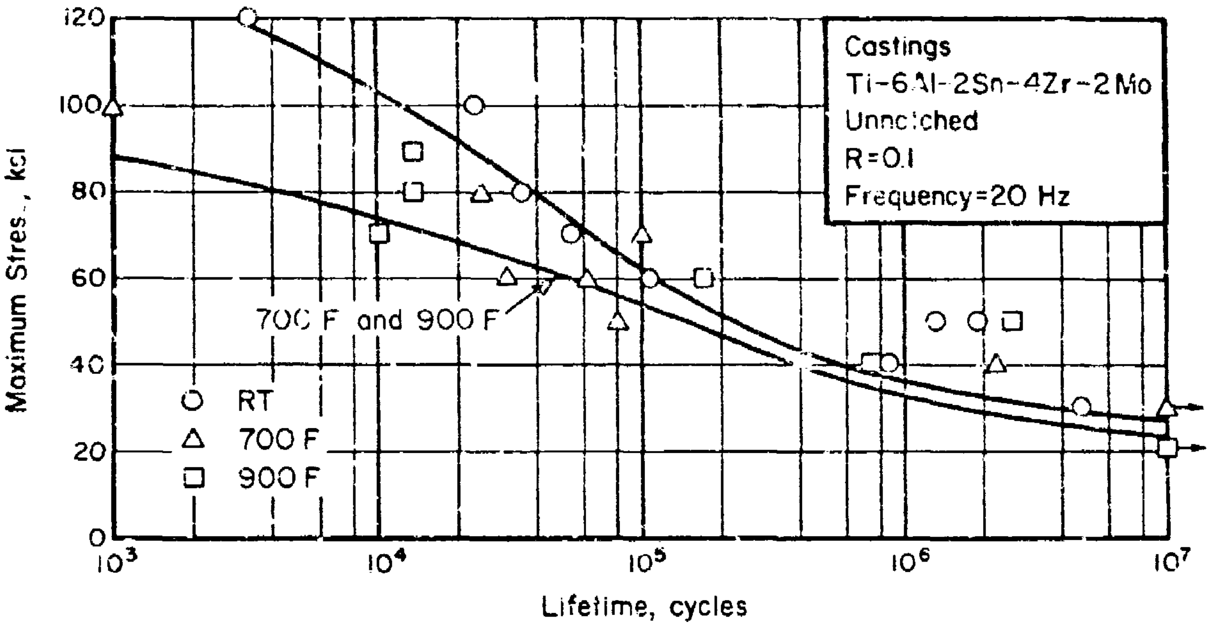

FIGURE 5. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED Ti-6Al-2Sn-4Zr-2Mo ALLOY CASTINGS

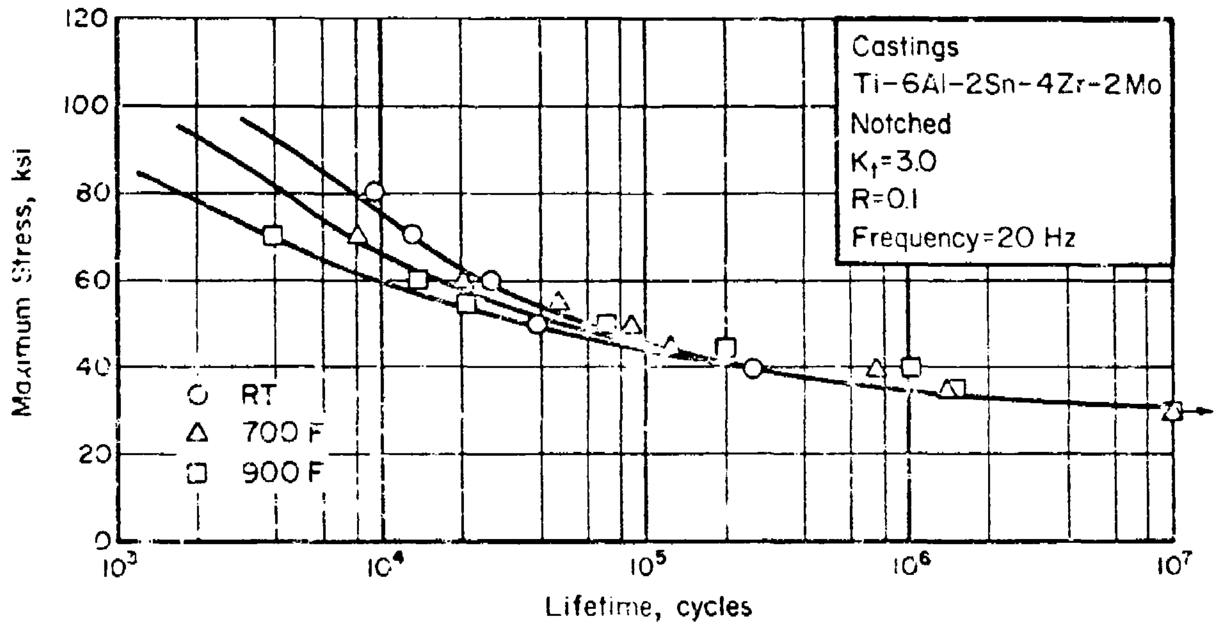

FIGURE 6. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) Ti-6Al-2Sn-4Zr-2Mo ALLOY CASTINGS

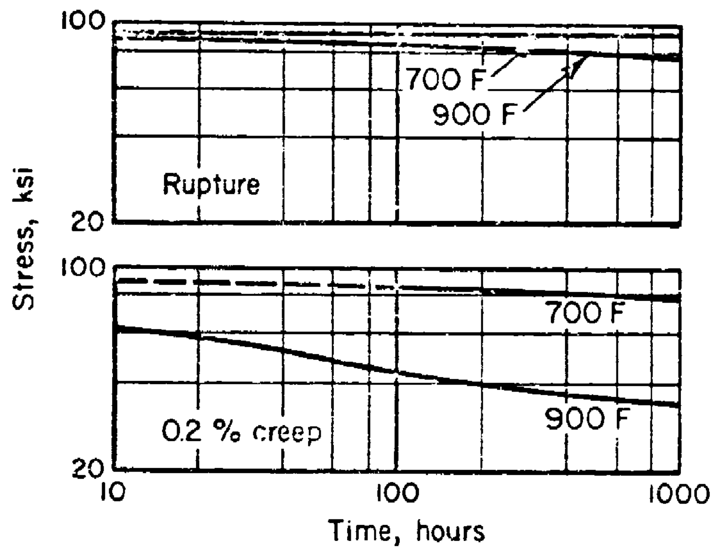

FIGURE 7. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR Ti-6Al-2Sn-4Zr-2Mo ALLOY CASTINGS

7175 Aluminum Alloy

Material Description

This aluminum alloy is a development of Alcoa and is primarily a high purity modification of the 7075 alloy. It was developed to provide improvements in mechanical properties, fracture toughness, and stress corrosion resistance over 7075. The material evaluated on this program was an extrusion about 3/4-inch thick by 24-inches wide by 24-inches long supplied by the Air Force.

Composition limits for 7175 are as follows:

Chemical Composition	Percent
Si	0.15 max
Fe	0.20 max
Cu	1.2 to 2.0
Mn	0.10 max
Cr	0.18 to 0.30
Zn	5.1 to 6.1
Ti	0.10 max
Mg	2.1 to 2.9
Others (Each)	0.05 max
Others (Total)	0.15 max
Al	balance

Processing and Heat Treating

The material was evaluated in the as-received -T73511 temper.

7175 Alloy Data[a]

Condition: -T73511

Thickness: ~ 3/4 x 24 x (L) Extrusion

Properties	Temperature, F RT	250	350
Tension			
TUS (longitudinal), ksi	77.1	62.3	46.8
TUS (transverse), ksi	76.3	61.4	46.2
TYS (longitudinal), ksi	66.3	60.2	41.0
TYS (transverse), ksi	64.9	58.9	38.0
e (longitudinal), percent in 1 inch	12.8	21.5	29.2
e (transverse), percent in 1 inch	12.0	19.7	26.7
RA (longitudinal), percent	35.5	50.9	60.0
RA (transverse), percent	27.6	45.0	54.9
E (longitudinal), 10^3 ksi	10.5	10.1	8.3
E (transverse), 10^3 ksi	10.9	10.6	8.6
Compression			
CYS (longitudinal), ksi	69.8	62.5	50.2
CYS (transverse), ksi	70.3	62.3	50.8
E_c (longitudinal), 10^3 ksi	10.1	10.1	9.6
E_c (transverse), 10^3 ksi	10.5	10.0	9.5
Bearing			
e/D = 1.5			
BUS (longitudinal), ksi	116.7	101.2	76.3
BUS (transverse), ksi	119.5	98.1	76.4
BYS (longitudinal), ksi	91.5	39.0	68.3
BYS (transverse), ksi	96.6	83.0	69.7
e/D = 2.0			
BUS (longitudinal), ksi	156.6	126.5	90.5
BUS (transverse), ksi	155.2	124.2	93.7
BYS (longitudinal), ksi	111.7	95.0	76.2
BYS (transverse), ksi	114.1	100.4	83.3

(Continued)

Properties	Temperature, F RT	250	350
Shear[b]			
SUS (longitudinal), ksi	44.0	39.4	30.8
SUS (transverse), ksi	44.4	40.8	32.6
Impact			
V-notch Charpy, ft.lbs.			
(longitudinal)	5.8	U[c]	U
(transverse)	5.0	U	U
Fracture Toughness[d]			
K_{Ic} (longitudinal)	26.2	U	U
K_{Ic} (transverse)	32.1	U	U
Axial Fatigue (transverse)			
Unnotched, R = 0.1			
10^3 cycles, ksi	70	60	54
10^5 cycles, ksi	50	39	33
10^7 cycles, ksi	43	31	26
Notched, K_t = 3.0, R = 0.1			
10^3 cycles, ksi	50	48	45
10^5 cycles, ksi	20	18	16
10^7 cycles, ksi	17	12	11
Stress Corrosion[e]			
80% TYS, 1000 hr maximum	no cracks		
Coefficient of Thermal Expansion			
12.5×10^{-6} inch/inch/F (68 to 212 F)			
Density			
0.101 lb./in.^{3}			

(a) Values are average of triplicate t s conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen; average of three tests in each direction.

(c) U, unavailable; NA, not applicable.

(d) Average of three tests in each direction.

(e) Room-temperature three-point bend test. Alternate immersion in 3-1/2% NaCl.

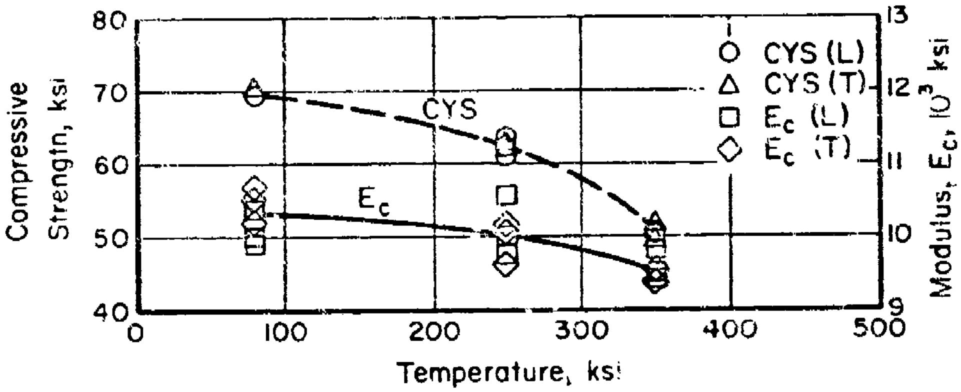

FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 7175-T73511 ALUMINUM ALLOY EXTRUSIONS

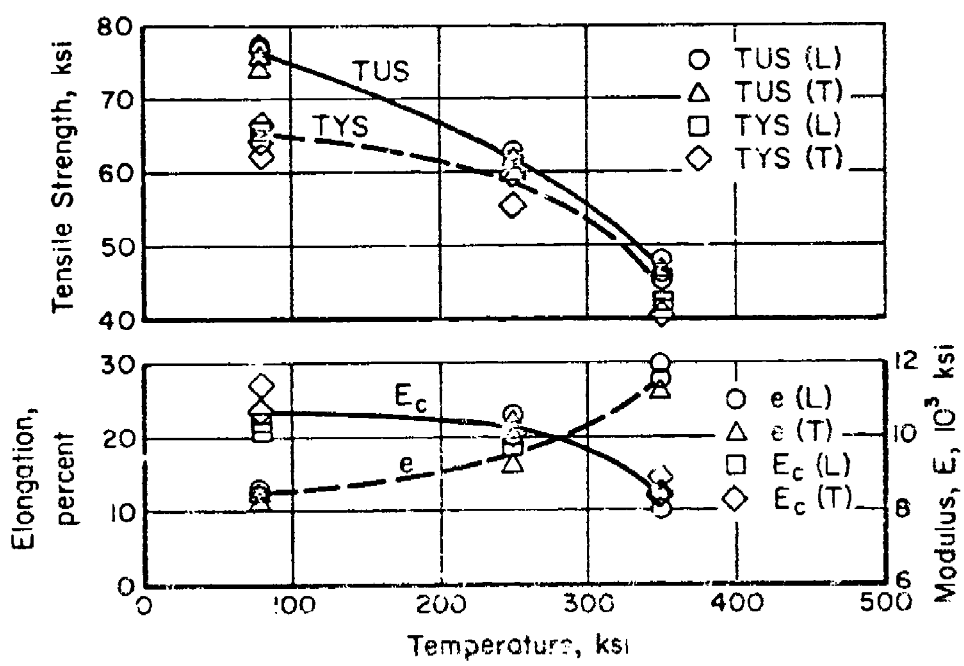

FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 7175-T73511 ALUMINUM ALLOY EXTRUSIONS

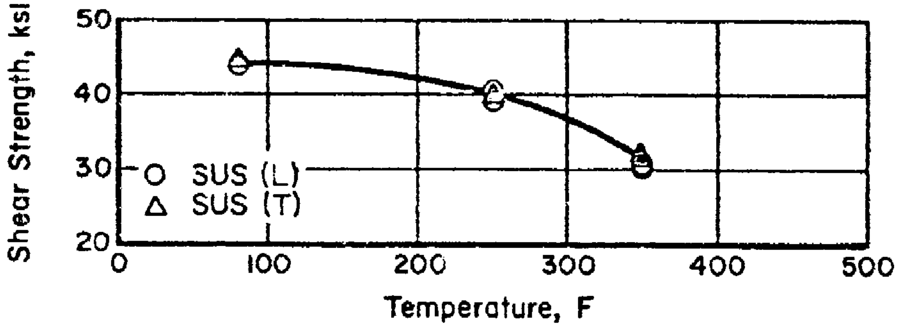

FIGURE 3. EFFECT OF TEMPERATURE ON THE SHEAR PROPERTIES OF 7175-T73511 ALUMINUM ALLOY EXTRUSIONS

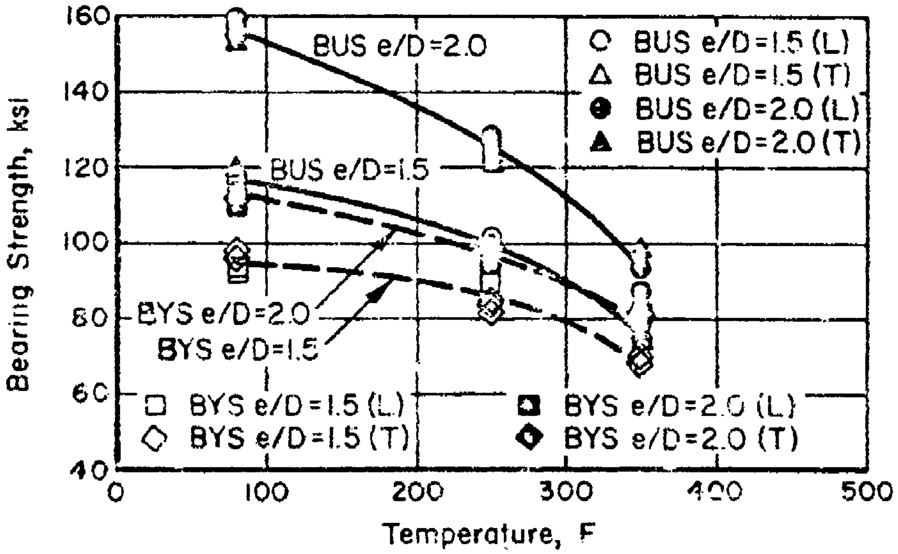

FIGURE 4. EFFECT OF TEMPERATURE ON THE BEARING PROPERTIES OF 7175-T73511 ALUMINUM ALLOY EXTRUSIONS

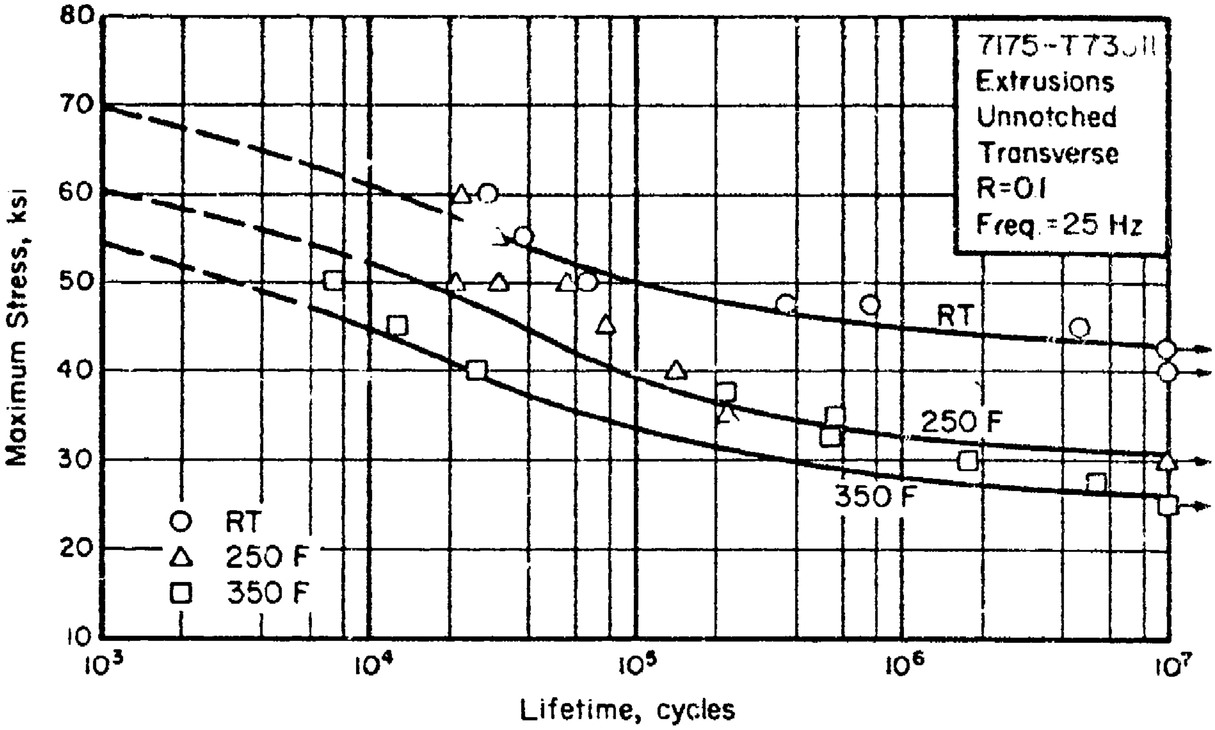

FIGURE 5. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED 7175-T73511 ALUMINUM ALLOY EXTRUSIONS

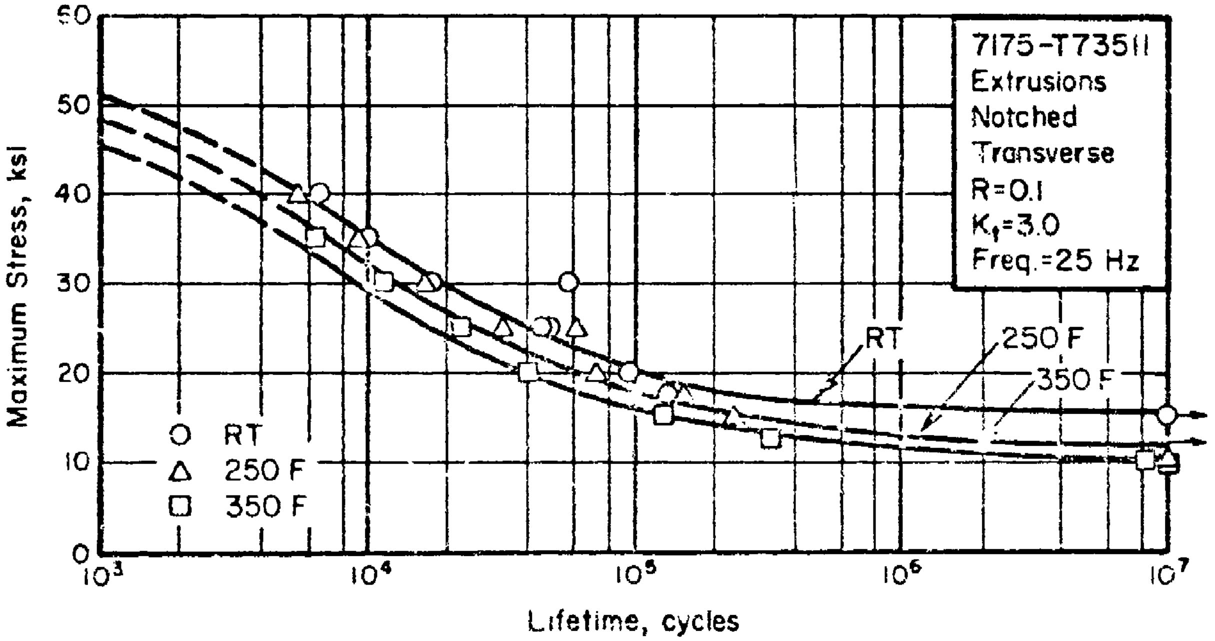

FIGURE 6. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) 7175-T73511 ALUMINUM ALLOY EXTRUSIONS

7050-T73 Aluminum Alloy

Material Description

Alloy 7050 is an Al-Zn-Mg-Cu alloy developed by the Alcoa Research Laboratories supported by the Naval Air Systems Command and the Air Force Materials Laboratory. When heat treated and aged to the -T73 temper, thick 7050 plate and hand forgings exhibit strengths equal to or exceeding those of 7079-T6XX products combined with improved fracture toughness and a high resistance to exfoliation and stress-corrosion cracking. The alloy differs from conventional 7XXX series aluminum alloys in that zirconium is added and chromium and manganese are restricted in order to minimize quench sensitivity.

The material used in this evaluation was an extrusion from Alcoa about 3/4-inch thick by 24 inches wide by 24 inches long. It was identified as Section 303002. Alloy 7050 is produced within the following composition limits.

Chemical Composition	Percent
Copper	2.0 to 2.8
Iron	0.15 max
Silicon	0.12 max
Manganese	0.10 max
Magnesium	1.9 to 2.6
Zinc	5.7 to 6.7
Chromium	0.04 max
Titanium	0.06 max
Aluminum	Balance.

Processing and Heat Treating

Specimens were tested in the as-received -T73 temper.

7050 Alloy Data[a]

Condition: -T73
Thickness: 3/4" approximate

Properties	Temperature, F RT	250	350
Tension			
TUS (longitudinal), ksi	77.4	62.7	50.3
TUS (transverse), ksi	75.8	60.5	49.0
TYS (longitudinal), ksi	67.5	61.4	49.6
TYS (transverse), ksi	66.1	58.6	48.6
e (longitudinal), percent in 2 in.	16	19	19
e (transverse), percent in 2 in.	13	16.7	15.3
RA (longitudinal), percent	45.4	53.5	63.4
RA (transverse), percent	34.0	48.2	56.7
E (longitudinal), 10^3 ksi	9.7	10.2	9.0
E (transverse), 10^3 ksi	9.7	9.7	9.4
Compression			
CYS (longitudinal), ksi	67.8	61.7	51.4
CYS (transverse), ksi	69.5	63.0	52.8
E_c (longitudinal), 10^3 ksi	10.3	10.1	8.6
E_c (transverse), 10^3 ksi	11.2	9.5	8.9
Bearing			
e/D = 1.5			
BUS (longitudinal), ksi	109.3	92.1	75.5
BUS (transverse), ksi	106.7	90.4	75.8
BYS (longitudinal), ksi	87.9	79.6	68.5
BYS (transverse), ksi	88.2	77.6	
e/D = 2.0			
BUS (longitudinal), ksi	149.9	116.8	94.6
BUS (transverse), ksi	146.4	116.3	92.8
BYS (longitudinal), ksi	106.0	93.5	77.5
BYS (transverse), ksi	108.9	95.6	75.6
Shear[b]			
SUS (longitudinal), ksi	46.1	36.5	29.8
SUS (transverse), ksi	44.5	35.0	28.9

7050 Alloy Data (Continued)

Properties	Temperature, F		
	RT	250	350
Impact			
V-notch Charpy, ft.lbs.(d)			
(longitudinal)	6.2	U(c)	U
(transverse)	6.2	U	U
Fracture Toughness			
K_{Ic} (longitudinal)	32.5	U	U
K_{Ic} (transverse)	33.2	U	U
Axial Fatigue (transverse)			
Unnotched, R = 0.1			
10^3 cycles, ksi	75	60	49
10^5 cycles, ksi	56	51	43
10^7 cycles, ksi	44	38	30
Notched, K_t = 3.0, R = 0.1			
10^3 cycles, ksi	55	50	47
10^5 cycles, ksi	20	17	13
10^7 cycles, ksi	11	10	10
Stress Corrosion(e)			
80 percent TYS, 1000 hr. max.	No cracks		
Coefficient of Thermal Expansion			
12.8×10^{-6} in/in/F (68 - 212 F)			
Density			
0.102 lb/in^3			

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.
(b) Double-shear pin-type specimen; average of three tests in each direction.
(c) U, unavailable; NA, not applicable.
(d) Average of three tests in each direction.
(e) Alternate immersion, 3½ percent NaCl.

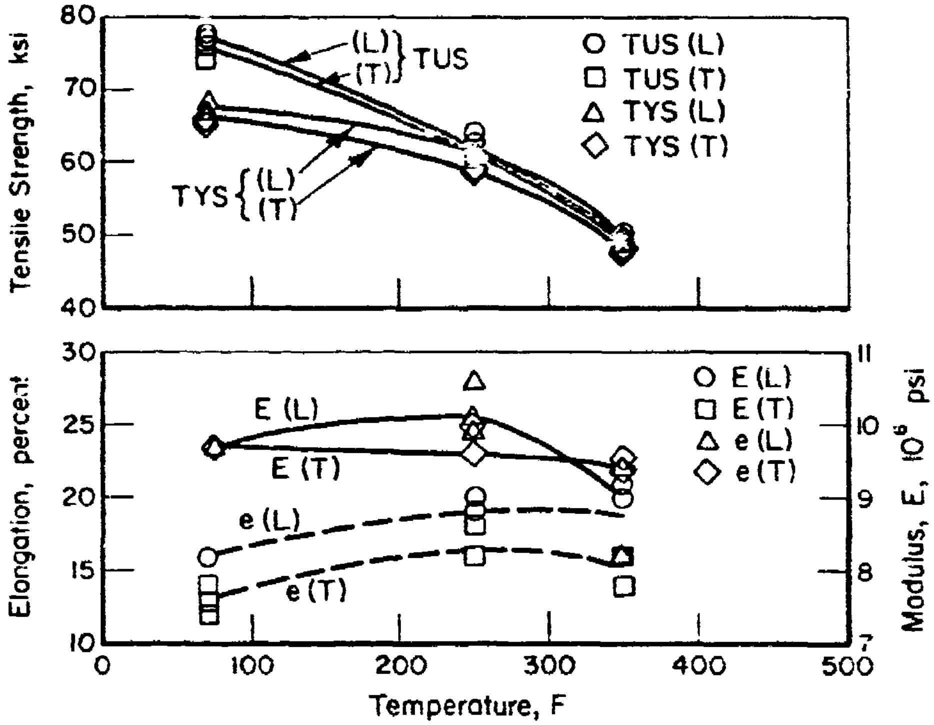

FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 7050-T73 ALUMINUM ALLOY EXTRUSIONS

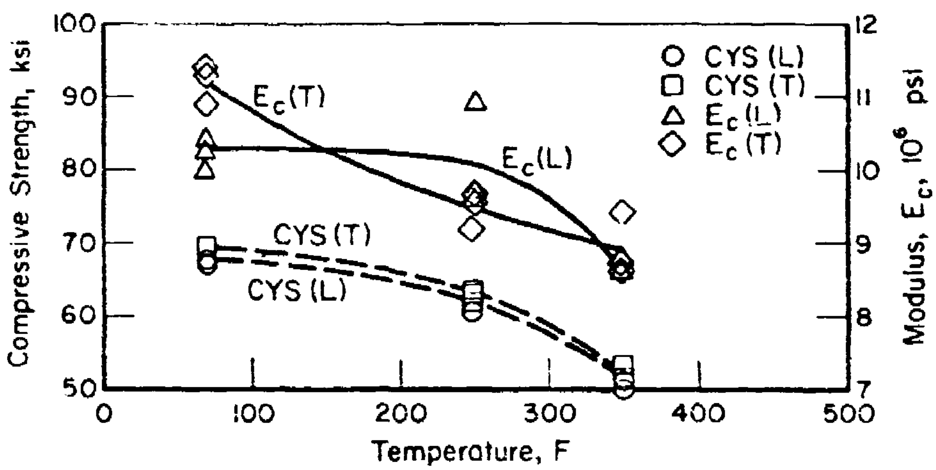

FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 7050-T73 ALUMINUM ALLOY EXTRUSIONS

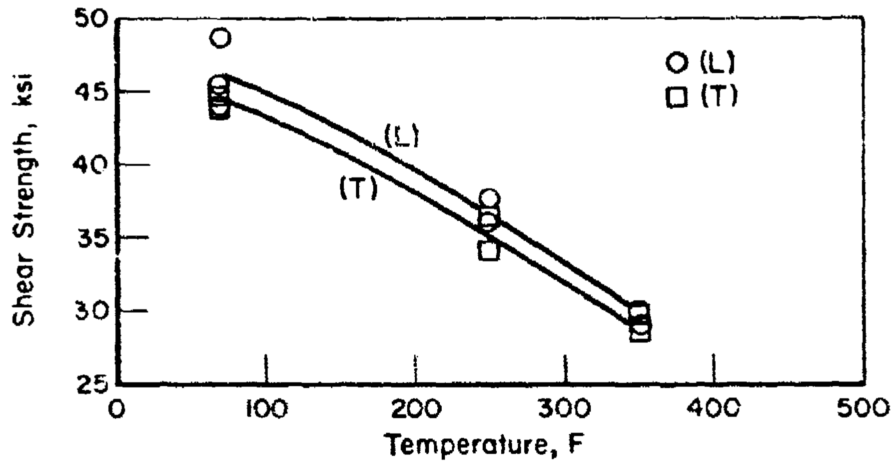

FIGURE 3. EFFECT OF TEMPERATURE ON THE SHEAR PROPERTIES OF 7050-T73 ALUMINUM ALLOY EXTRUSIONS

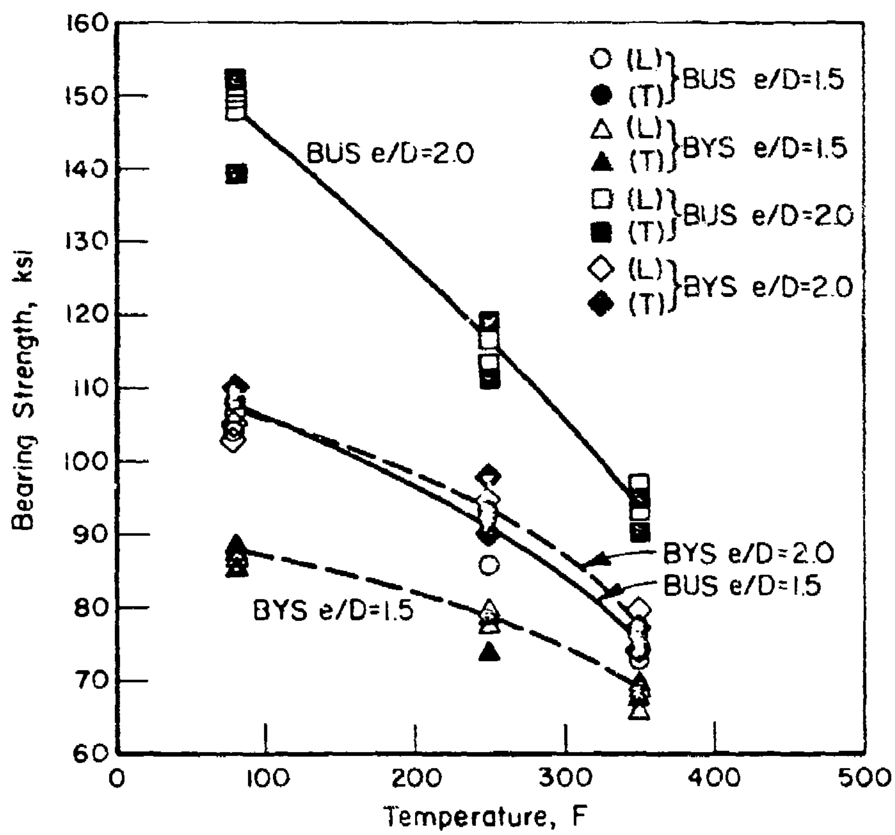

FIGURE 4. EFFECT OF TEMPERATURE ON THE BEARING PROPERTIES OF 7050-T73 ALUMINUM ALLOY EXTRUSIONS

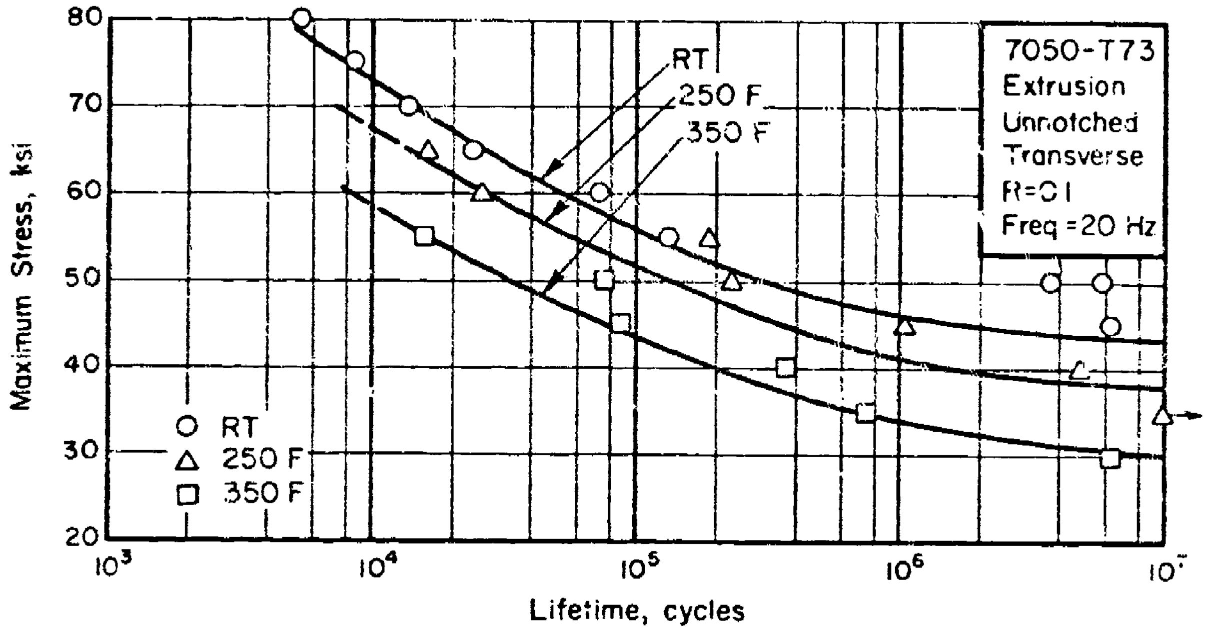

FIGURE 5. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED 7050-T73 ALUMINUM ALLOY EXTRUSIONS

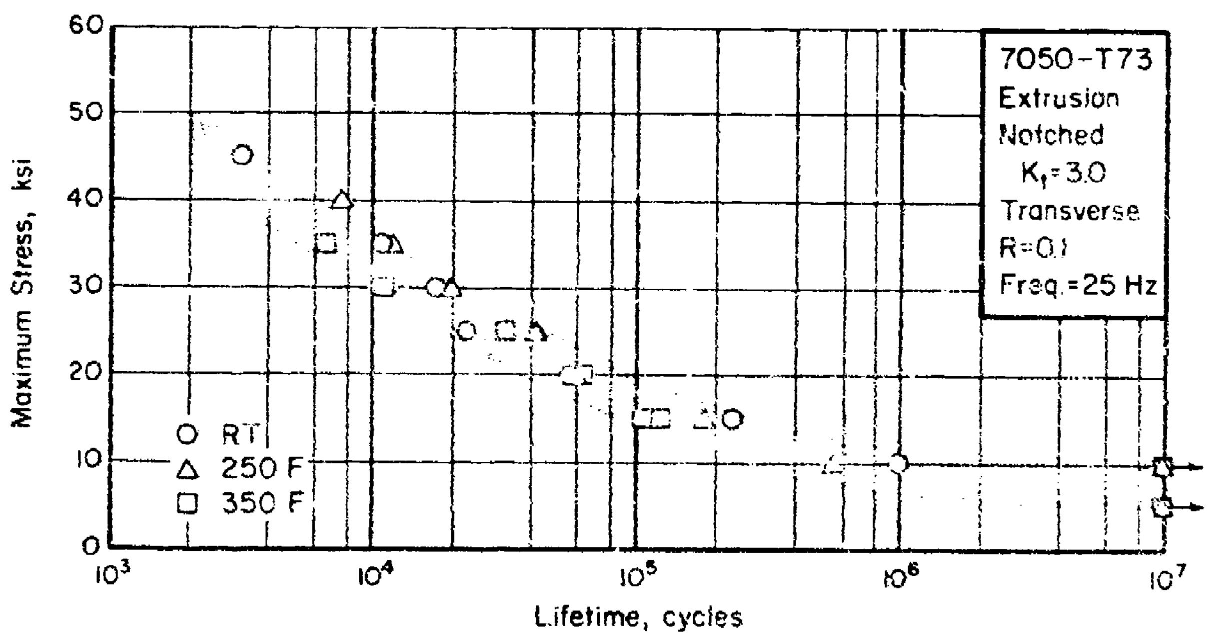

FIGURE 6. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) 7050-T73 ALUMINUM ALLOY EXTRUSIONS

Ti-6Al-4V PM Product

Material Description

The material used for this evaluation was Ti-6Al-4V pressed and vacuum sintered to 94 percent minimum density. It was supplied by Dynamet Technology and produced as part of current manufacturing production run for various parts, it varied in cross section and length from 2 inches x 1 inch x 6 inches to smaller sizes.

Processing and Heat Treating

The material was evaluated in the as-received condition as described above. Specimens were selected from various section sizes of the total of 90 inches (12 pieces) of material.

Ti-6Al-4V PM Alloy Data[a]

Condition: Pressed ıd Sintered
Thickness: Variou

Properties	Temperature, F RT	400	800
Tension			
TUS (longitudinal), ksi	106.1	78.6	62.0
TYS (longitudinal), ksi	92.4	67.3	45.7
e (longitudinal), percent in 1 in.	5.0	4.5	8.0
RA (longitudinal), percent	4.9	7.9	8.5
E (longitudinal), 10^3 ksi	15.3	13.5	12.0
Compression			
CYS (longitudinal), ksi	97.7	70.7	50.0
E_c (longitudinal), 10^3 ksi	14.5	12.6	11.3
Bearing			
e/D = 1.5			
BUS, ksi	176.8	139.3	114.3
BYS, ksi	151.3	117.8	94.2
e/D = 2.0			
BUS, ksi	225.5	169.1	141.8
BYS, ksi	173.0	134.1	105.9
Shear[b]			
SUS (longitudinal), ksi	72.6	59.8	45.7
Impact			
V-notch Charpy, ft.lbs. (longitudinal)	13.5[d]	U[c]	U
Fracture Toughness[e]			

Ti-6Al-4V PM Alloy Data (Continued)

Properties	Temperature, F RT	400	800
<u>Axial Fatigue (transverse)</u>			
Unnotched, R = 0.1			
10^3 cycles, ksi	100	80	80
10^5 cycles, ksi	47	40	40
10^7 cycles, ksi	20	30	30
Notched, K_t = 3.0, R = 0.1			
10^3 cycles, ksi	50	46	40
10^5 cycles, ksi	26	34	25
10^7 cycles, ksi	12	22	20
<u>Stress Corrosion</u>			
80% TYS, 1000 hrs. maximum	no cracks[(f)]		
<u>Coefficient of Thermal Expansion</u>			
6.2×10^{-6} in./in./F (70-800 F)			
<u>Density</u>			
0.151 lb./in.^{3}			

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen; average of three tests in each direction.

(c) U, unavailable; NA, not applicable.

(d) Average of five tests.

(e) Material of insufficient size for fracture tests.

(f) Alternate immersion, 3½% NaCl.

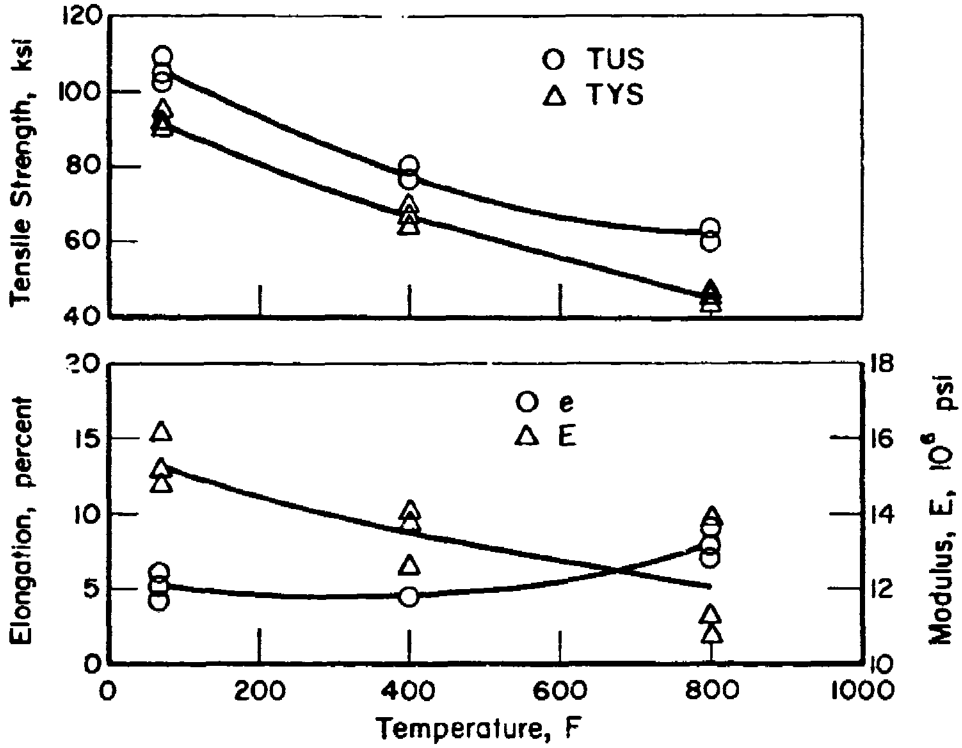

FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF Ti-6Al-4V PM PRODUCT

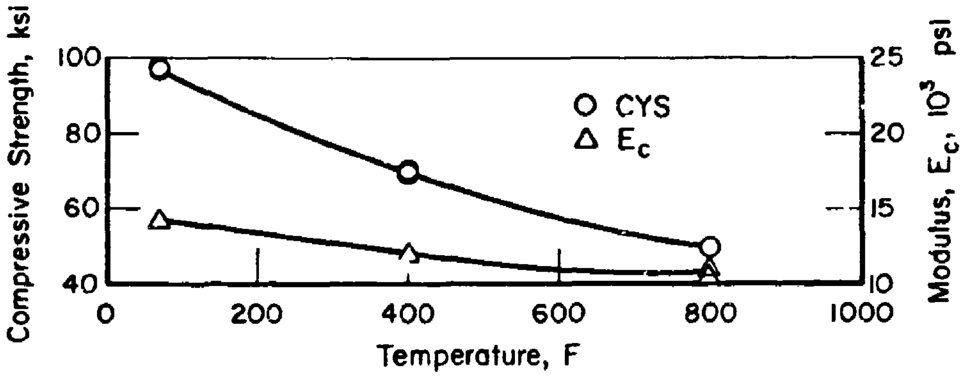

FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF Ti-6Al-4V PM PRODUCT

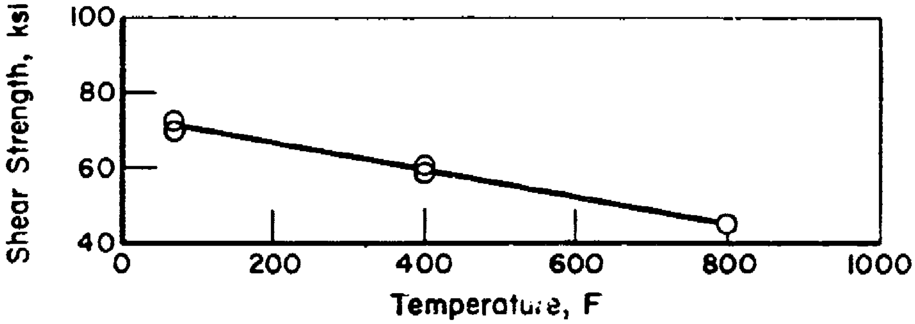

FIGURE 3. EFFECT OF TEMPERATURE ON THE SHEAR PROPERTIES OF Ti-6Al-4V PM PRODUCT

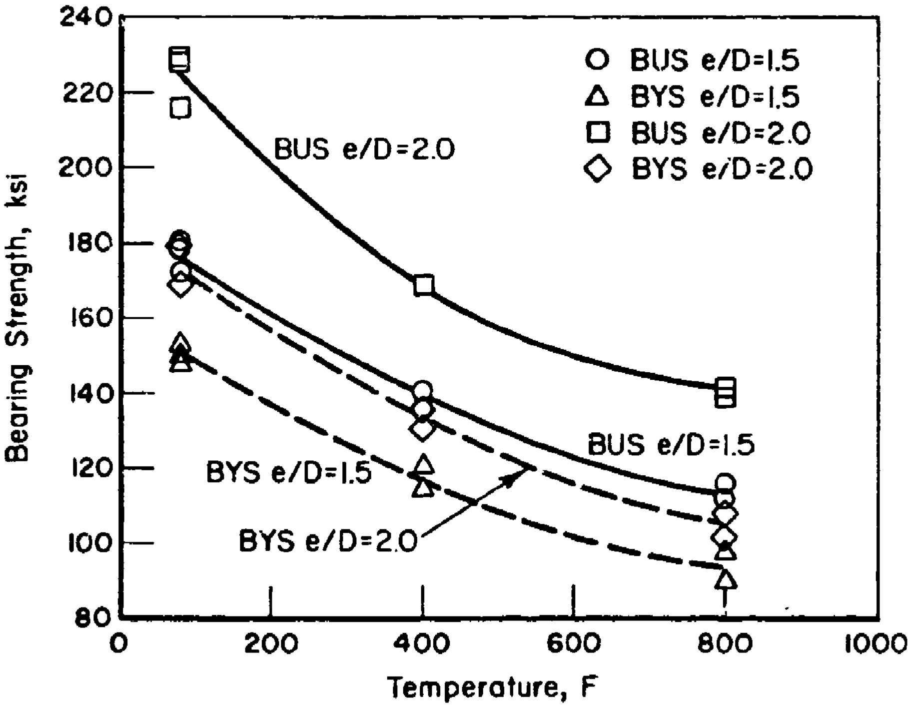

FIGURE 4. EFFECT OF TEMPERATURE ON THE BEARING PROPERTIES OF Ti-6Al-4V PM PRODUCT

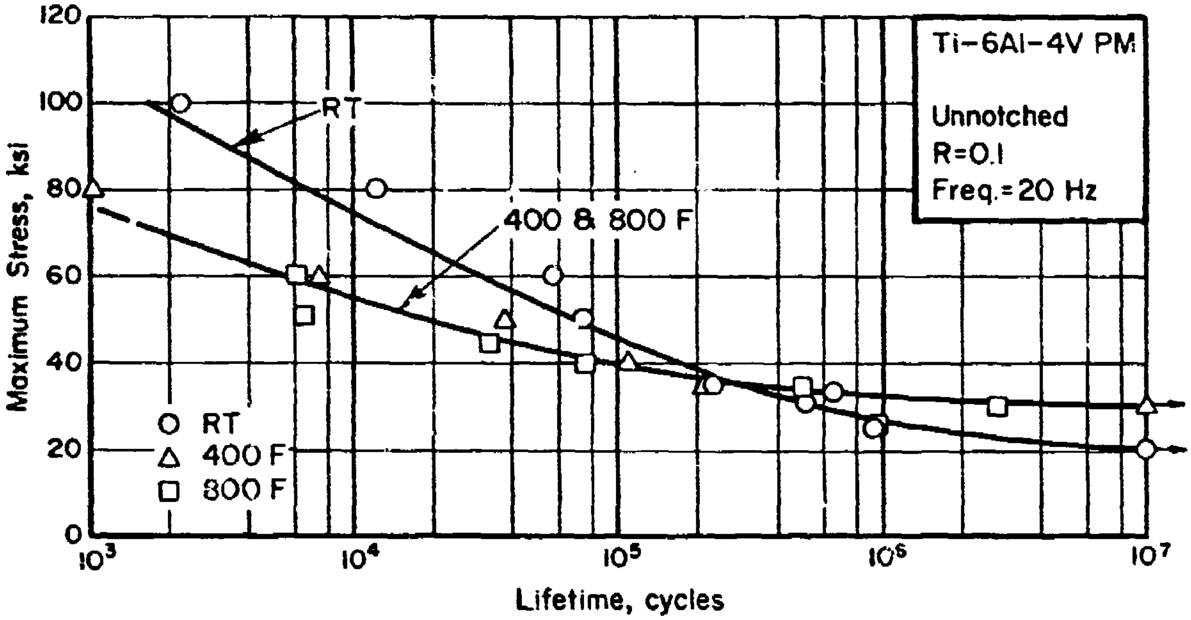

FIGURE 5. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED Ti-6Al-4V PM PRODUCT

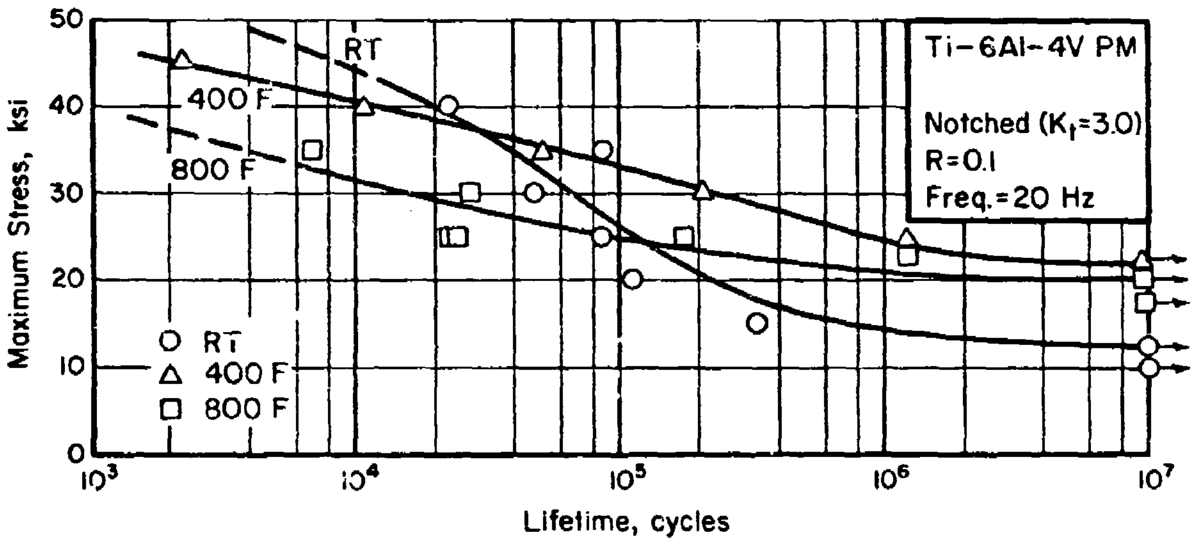

FIGURE 6. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) Ti-6Al-4V PM PRODUCT

Superplastically Formed Ti-6Al-4V Alloy

Material Description

The material used for this evaluation was Ti-6Al-4V superplastically formed as described in AFML-TR-75-62, "Superplastic Forming of Titanium Structures". Two nacelle forward center beam frames resulting from the program described in AFML-TR-75-62 were supplied by the Air Force. Extensive information regarding the material, forming processes, and material properties may be found in the AFML Technical Report.

Processing and Heat Treating

The area of flat material from which to section specimens was limited. Also it was discovered that the thickness varied in the available flat areas and it was necessary to surface grind the specimens obtained. Only tensile, compression, and fatigue specimens were available from the material.

Ti-6Al-4V Alloy Data[a]

Condition: Superplastically Formed
Thickness: 0.040 - 0.080

Properties	Temperature, F RT	400	800
Tension			
TUS (transverse), ksi	139.9	110.7	92.8
TYS (transverse), ksi	127.3	91.7	71.1
e (transverse), percent in 1 in.	15.5	11.5	10.0
E (transverse), 10^3 ksi	17.7	15.0	15.9
Compression			
CYS (transverse), ksi	122.7	105.7	70.3
E_c (transverse), 10^3 ksi	17.4	14.6	14.3
Axial Fatigue (Transverse)			
Unnotched, R = 0.1			
10^3 cycles, ksi	100	95	
10^5 cycles, ksi	57	40	
10^7 cycles, ksi	(38)	(20)	
Notched, K_t = 3.0, R = 0.1			
10^3 cycles, ksi	77	77	
10^5 cycles, ksi	32	32	
10^7 cycles, ksi	15	20	

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

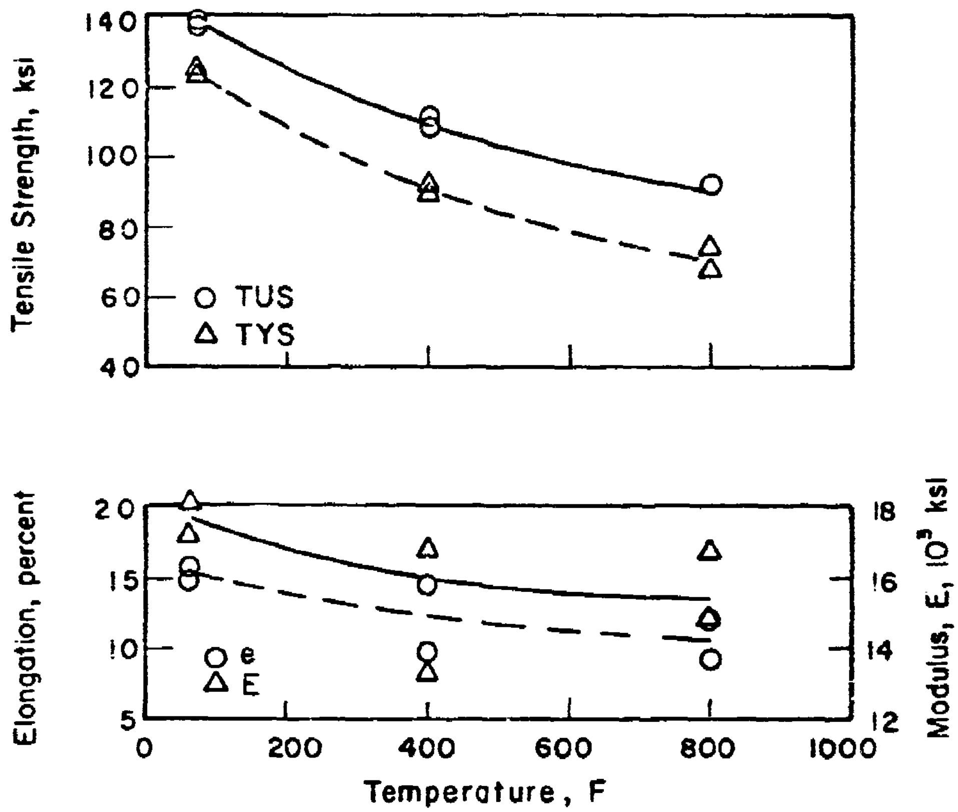

FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF SUPERPLASTICALLY FORMED Ti-6Al-4V ALLOY

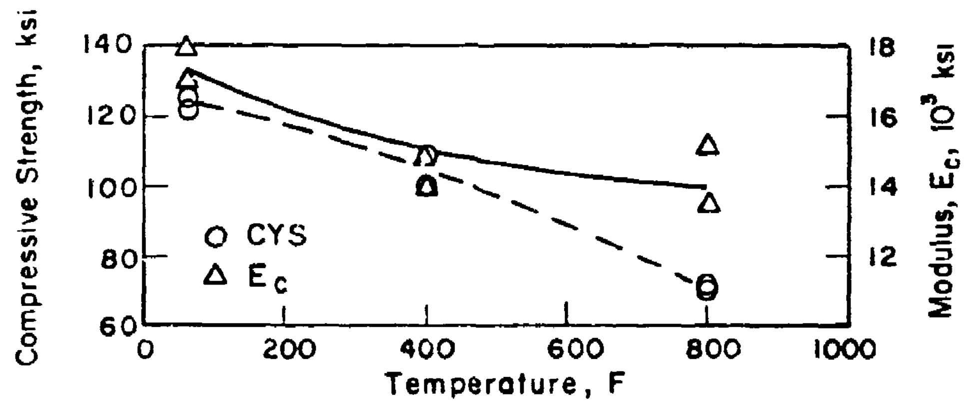

FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF SUPERPLASTICALLY FORMED Ti-6Al-4V ALLOY

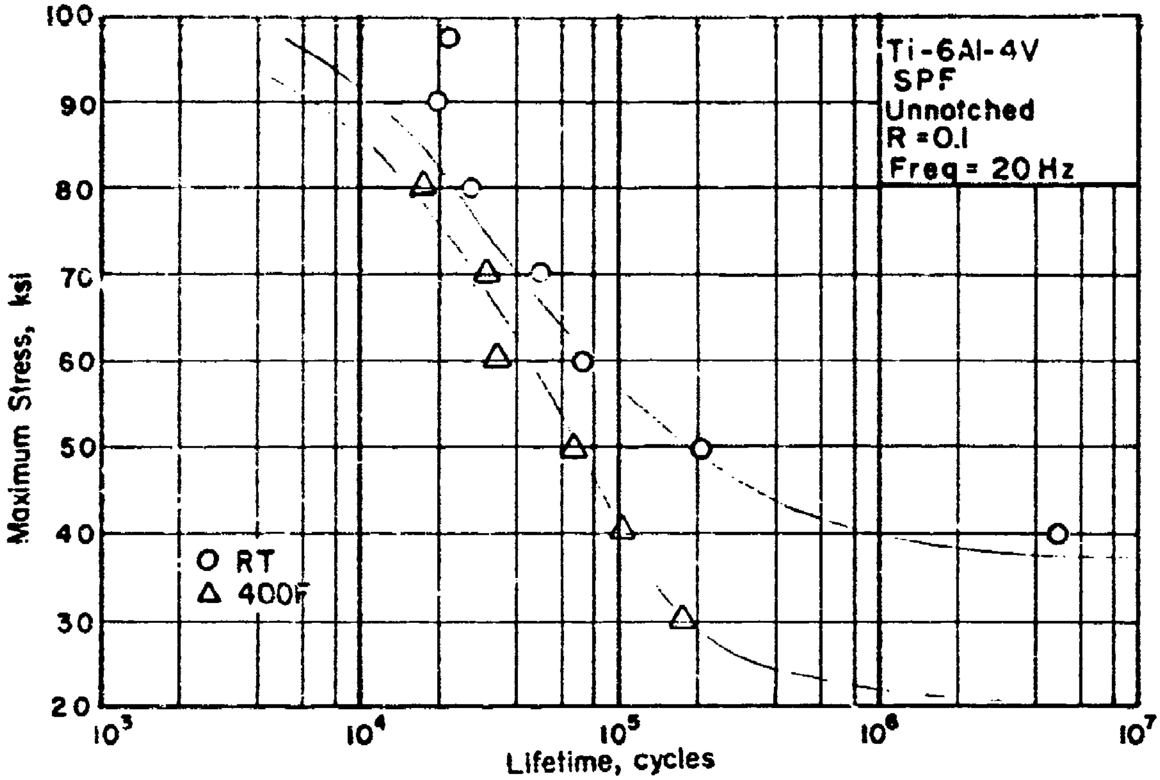

FIGURE 3. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED SUPERPLASTICALLY FORMED Ti-6Al-4V ALLOY

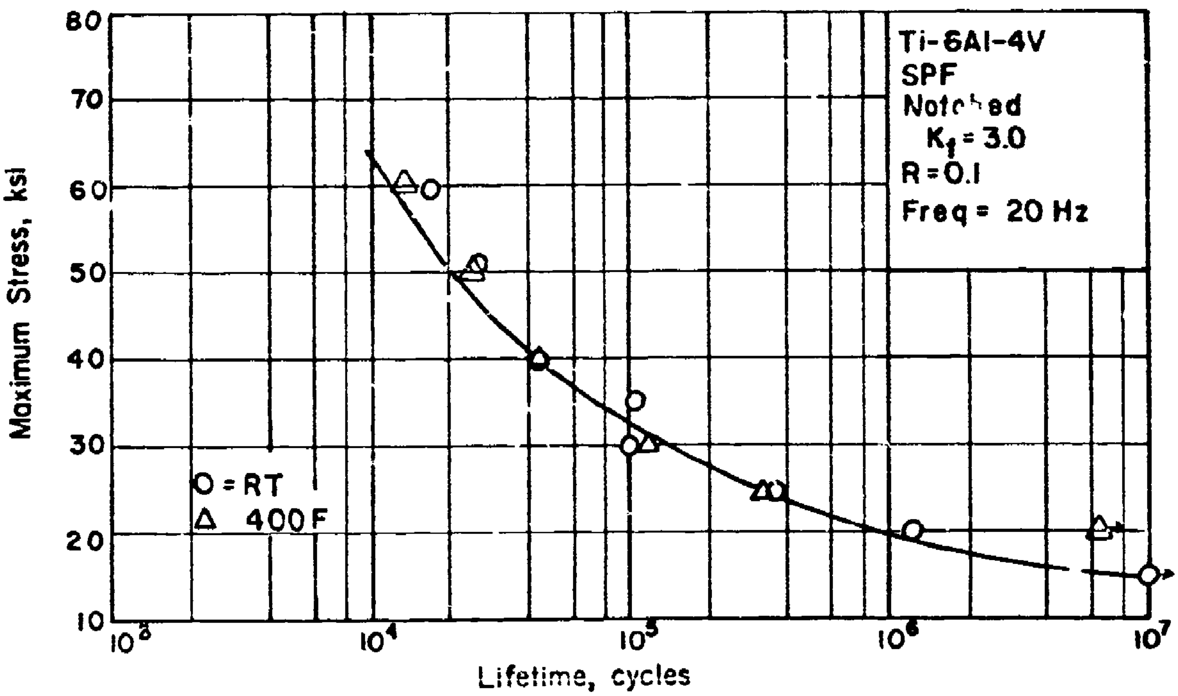

FIGURE 4. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) SUPERPLASTICALLY FORMED Ti-6Al-4V ALLOY

Ti-10V-2Fe-3Al Alloy

Material Description

This alloy is a recent development of TIMET, a division of Titanium Metals Corporation of America. The alloy, metallurgically near-beta, is a high fracture toughness composition and is capable of attaining a variety of strength levels, depending on the selection of heat treatment. In the solution-treated and aged condition, the alloy shows creep-stability characteristics similar to the alpha-beta alloys at 600 F. A major advantage, other than toughness, is its excellent forgeability. It moves readily at temperatures below those required for Ti-6Al-4V.

TIMET believes the alloy should be considered for applications up to 600 F where medium to high strength and high toughness are required in sections up to five inches thick.

The nominal composition of Ti-10V-2Fe-3Al is:

Chemical Composition	Percent
Al	2.6 - 3.4
V	9.0 - 11.0
Fe	1.8 - 2.2
O	0.16 max
C	0.05 max
N	0.05 max
H	0.015 max
Others, Each	0.10 max
Others, Total	0.30 max

The material used for this evaluation was 3-inch round bar from TIMET heat P-1452.

Processing and Heat Treating

The material was heat treated as follows: 1 hour at 1400 F, furnace cooled plus 8 hours at 1050 F, air cooled. This is an intermediate strength, STOA condition. All specimens were sectioned in the longitudinal direction from the bar.

Ti-10V-2Fe-3Al Alloy Data[a]

Condition: STOA
Thickness: 3" Round Bar

Properties	Temperature, F RT	400	800
Tension			
TUS (longitudinal), ksi	141.5	119.8	97.2
TYS (longitudinal), ksi	137.7	106.4	78.9
e (longitudinal), percent in 1 in.	18.3	21.3	22.3
RA (longitudinal), percent	62.5	65.6	79.5
E (longitudinal), 10^3 ksi	14.7	14.0	11.4
Compression			
CYS (longitudinal), ksi	139.6	107.4	80.1
E_c (longitudinal), 10^3 ksi	15.4	14.3	12.6
Bearing			
e/D = 1.5			
BUS (longitudinal), ksi	239.3	198.7	153.0
BYS (longitudinal), ksi	190.0	159.0	132.3
e/D = 2.0			
BUS (longitudinal), ksi	290.3	258.3	195.0
BYS (longitudinal), ksi	226.3	192.0	153.3
Shear[b]			
SUS (longitudinal), ksi	97.2	82.3	67.0
Impact[d]			
V-notch Charpy, ft.lbs.			
(longitudinal)	28.8	U[c]	U
(transverse)	19.0	U	U
Fracture Toughness			
K_{Ic} (longitudinal)	77.4[e]	NA	NA

(Continued)

Properties	Temperature, F RT	400	800
Axial Fatigue (Longitudinal)			
Unnotched, R = 0.1			
10^3 cycles, ksi	150	120	110
10^5 cycles, ksi	130	110	75
10^7 cycles, ksi	110	102	65
Notched, K_t = 3.0, R = 0.1			
10^3 cycles, ksi	80	80	80
10^5 cycles, ksi	21	21	21
10^7 cycles, ksi	15	15	15
Creep (longitudinal)	700 F	900 F	
0.2% plastic deformation, 100 hr, ksi	25	13	
0.2% plastic deformation, 1000 hr, ksi	3.2	1.2	
Stress Rupture (Longitudinal)			
Rupture, 100 hr, ksi	91	85	
Rupture, 1000 hr, ksi	27	14	
Stress Corrosion			
80% TYS, 1000 hr maximum	No Cracks (f)	U	
Coefficient of Thermal Expansion			
5.4×10^{-6} in./in./F (RT to 800 F)			
Density			
0.168 lb./in.^{3}			

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.
(b) Double-shear pin-type specimen; average of three tests in each direction.
(c) U, unavailable; NA, not applicable.
(d) Average of three tests.
(e) Average of four tests.
(f) Alternate immersion, 3.5% NaCl.

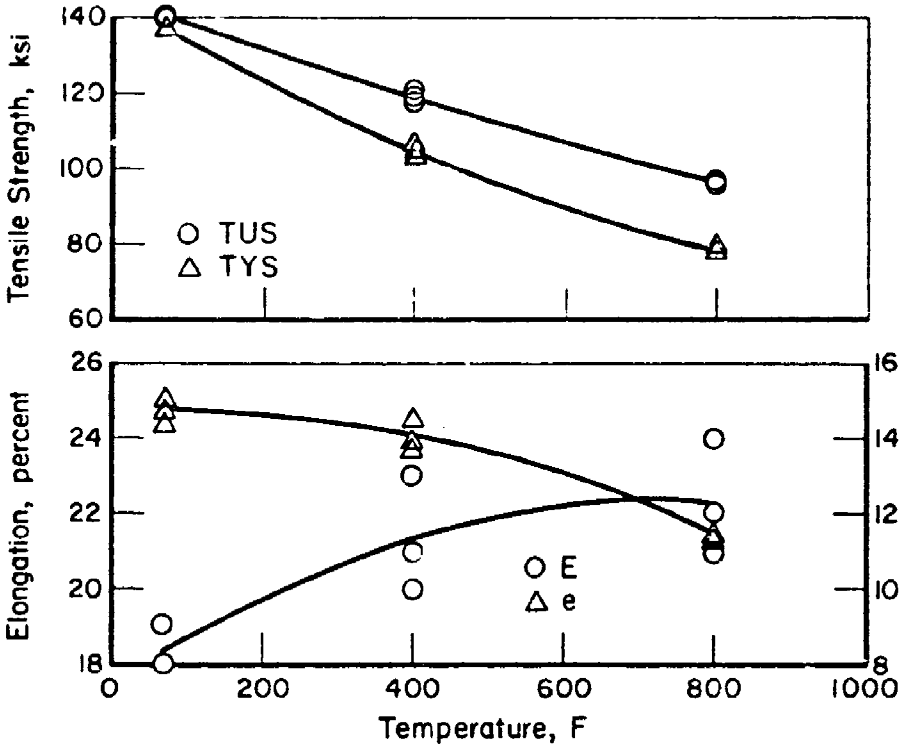

FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF STOA Ti-10V-2Fe-3Al ROUND BAR

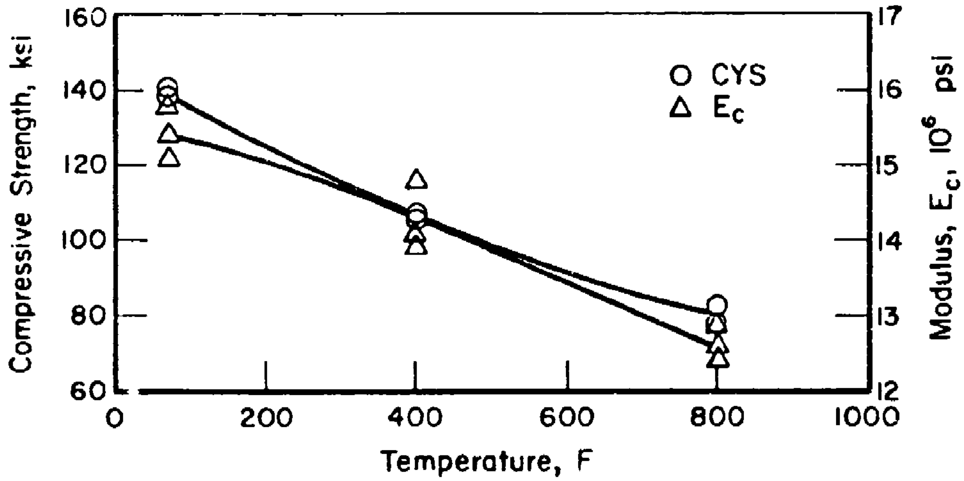

FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF STOA Ti-10V-2Fe-3Al ROUND BAR

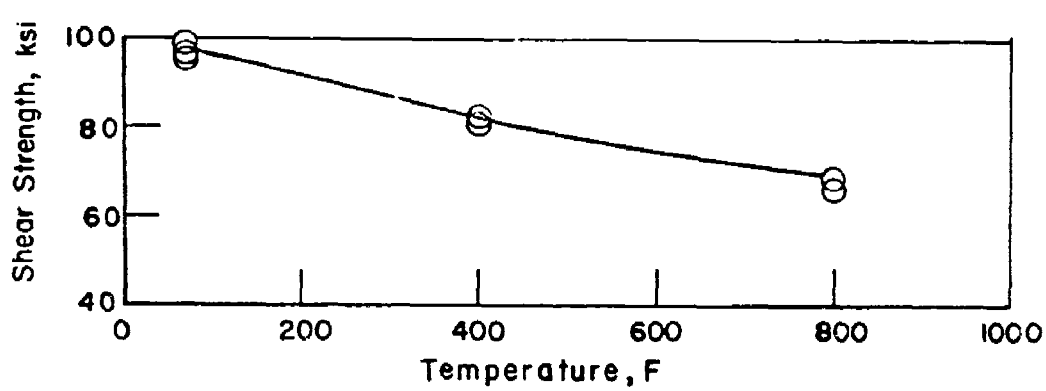

FIGURE 3. EFFECT OF TEMPERATURE ON THE SHEAR PROPERTIES OF STOA Ti-10V-2Fe-3Al ROUND BAR

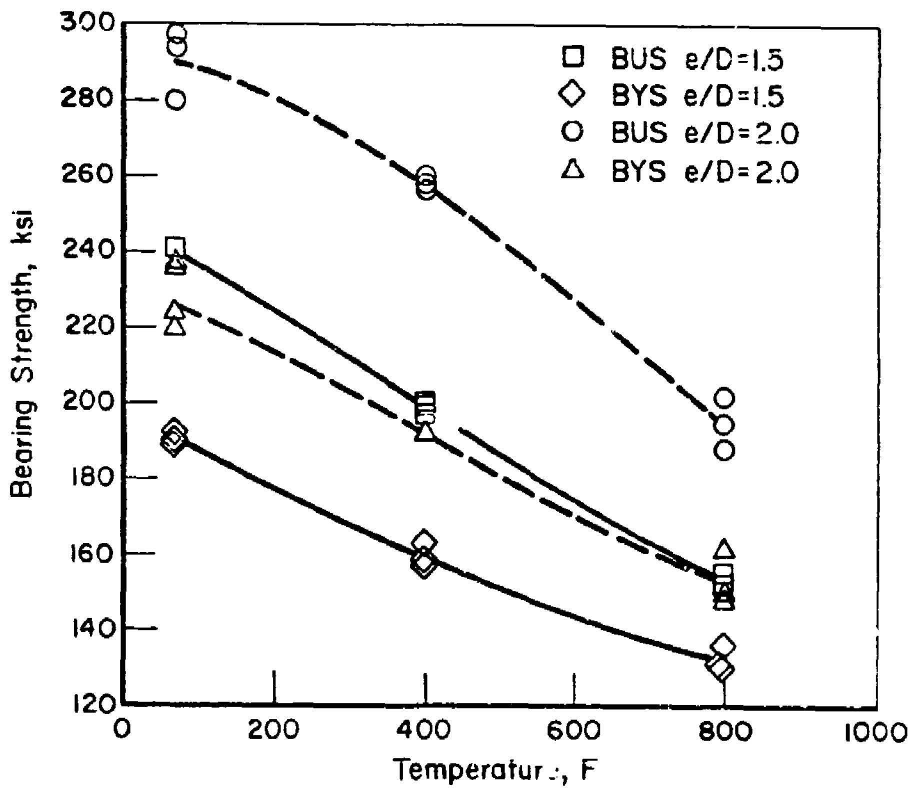

FIGURE 4. EFFECT OF TEMPERATURE ON THE BEARING PROPERTIES OF STOA Ti-10V-2Fe-3Al ROUND BAR

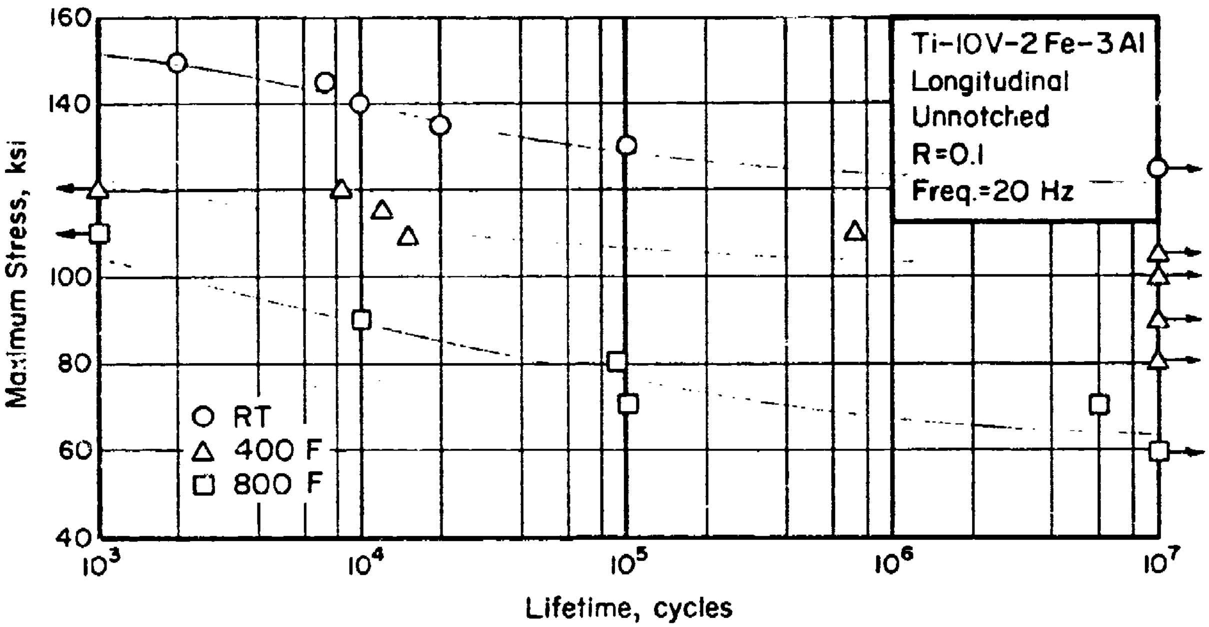

FIGURE 5. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED STOA Ti-10V-2Fe-3Al ROUND BAR

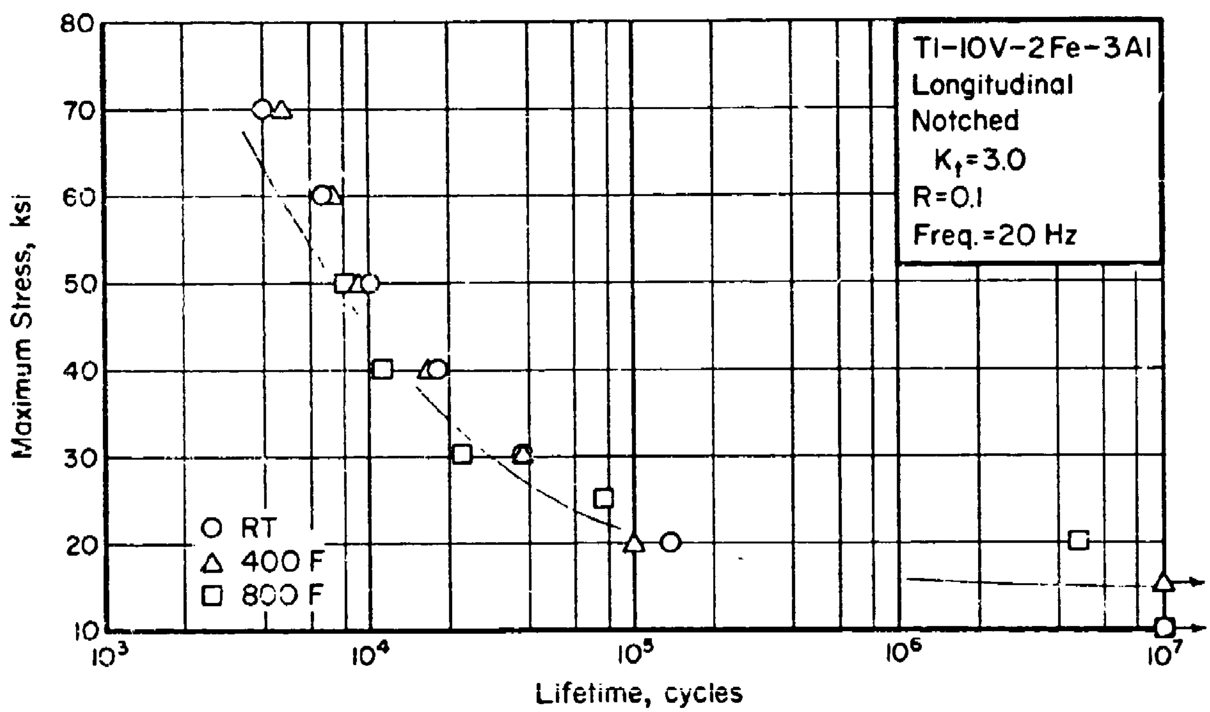

FIGURE 6. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) STOA Ti-10V-2Fe-3Al ROUND BAR

4330M Steel Forgings

Material Description

A limited evaluation of 4330M forgings, related to a service problem, was performed as a modification to the contract. The material was a forging used in airframe structure related to the horizontal stabilizer of the F-5E.

Processing and Heat-Treating

The forgings were heat-treated (quenched and tempered) to the 220-240 ksi tensile strength level. As directed, only limited room temperature tests were performed.

4330M Data[a]

Condition: Heat Treated
Thickness: Varying thickness forging

Properties	Room Temperature
Tension	
TUS (longitudinal), ksi	244.4
TUS (transverse), ksi	242.4
TYS (longitudinal), ksi	203.8
TYS (transverse), ksi	202.4
e (longitudinal), percent in 1 inch	12.3
e (transverse), percent in 1 inch	12.0
RA (longitudinal), percent	50.0
RA (transverse), percent	48.4
E (longitudinal), 10^3 ksi	28.9
E (transverse), 10^3 ksi	29.0
Compression	
CYS (longitudinal), ksi	221.4
CYS (transverse), ksi	221.9
E_c (longitudinal), 10^3 ksi	29.3
E_c (transverse), 10^3 ksi	29.6
Shear[b]	
SUS (longitudinal), ksi	159.6
SUS (transverse). ksi	157.1
Impact, Charpy V-Notch	
Longitudinal, ft. lbs.	15.3
Transverse, ft. lbs.	14.2

Properties	Room Temperature
Fracture Toughness(c)	
K_{Ic}, ksi$\sqrt{in.}$ (T-ST)	76.3
Axial Fatigue (Transverse)(d)	
Unnotched, R=0.1	
10^3 cycles, ksi	236
10^5 cycles, ksi	196
10^7 cycles, ksi	175
Notched, K_t = 3.0, R=0.1	
10^3 cycles, ksi	184
10^5 cycles, ksi	70
10^7 cycles, ksi	65
Density	
0.283 lb./in.^{3}	

(a) Values given are average of triplicate tests conducted at Battelle Columbus under the subject contract unless otherwise indicated. Values for fatigue are from curves generated using a greater number of tests.

(b) Double-shear pin-type specimen.

(c) Compact tension-type specimen.

(d) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

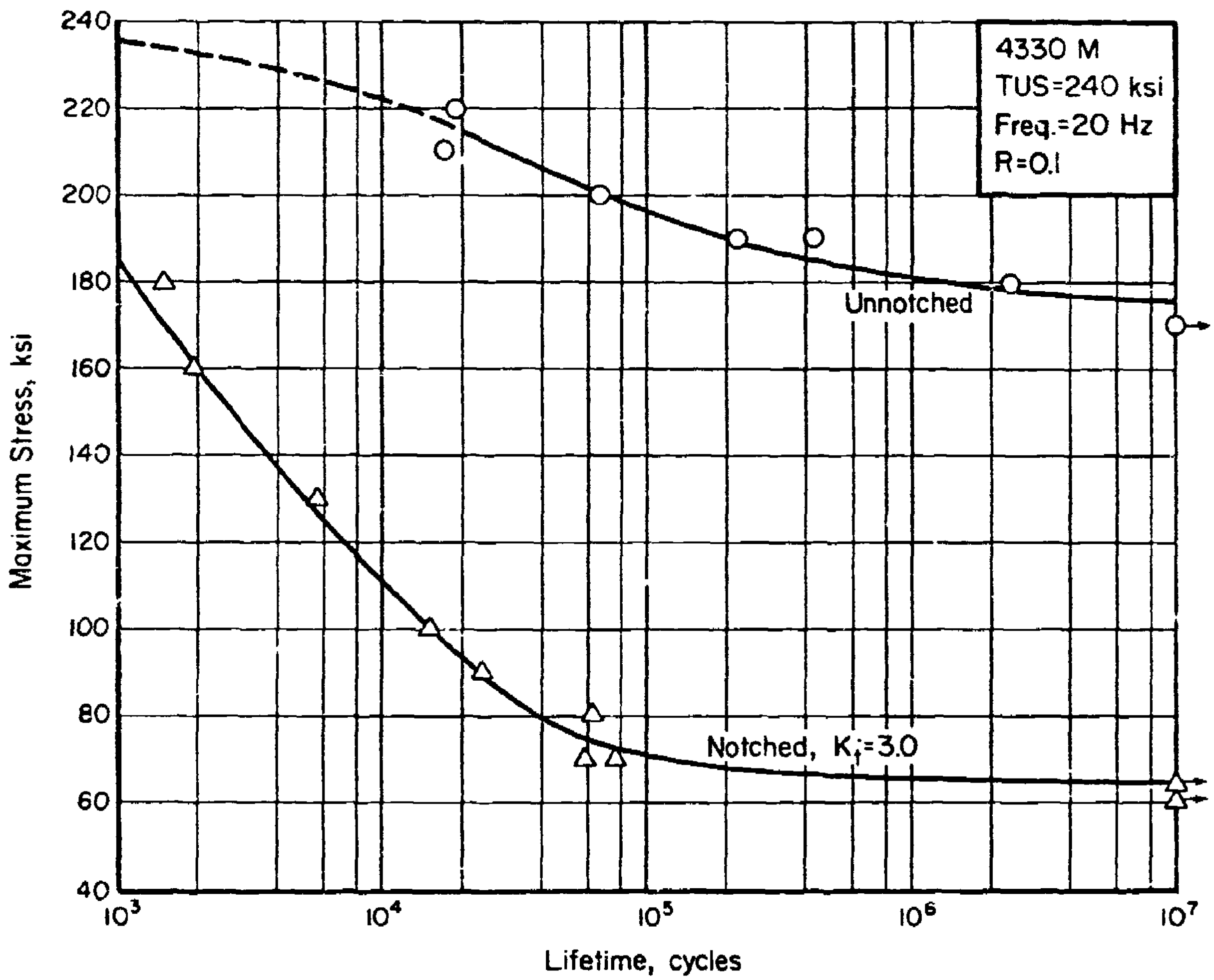

FIGURE 1. AXIAL-LOAD-FATIGUE BEHAVIOR OF 4330M AT ROOM TEMPERATURE

*U.S.Government Printing Office: 1978 — 757-030/441